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The drawing on the cover is of the barque Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

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ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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Symbolism in science

In the present issue we publish an article by Mr D. I. Duveen on symbols used by the alchemists. This may direct our attention to the wider topic of the place of symbols and symbolism in science as a whole—a topic of considerable practical importance no less than of historical and philosophical interest. It is pertinent to recall that the original meaning of the word symbol was a creed or a confession of faith, for in effect that is the significance of many scientific symbols of today. When, for example, we say that the gravitational force f between two masses m_1 and m_2 at a distance a is equal to $k \times (m_1 . m_2)/a^2$, we are expressing the belief of the scientist that any two masses will in fact be found to behave in this way. In the same way the basic curve of the horse-chestnut leaf may be represented as $r = \sin(\theta/2) . \sin n\theta$, though perhaps the affirmation of belief in this case is not accompanied by such a profound conviction of its universality.

The use of symbols in science is well known to be of great antiquity, and to have early acquired a sophisticated character. Thus in a Babylonian tablet of the seventeenth century B.C., dealing with the preparation of a lead glaze coloured with copper, the Sumerian ideogram for 'eagle' is used. This sign has the Semitic value of *erû*, meaning copper, which is obviously the sense in which the initiated reader is expected to interpret it. Commoner than this punning source of symbols was their derivation from the natural occurrence of substances; so sulphur, for instance, which is sometimes to be found floating on Mesopotamian streams, was known to the Assyrians as *kibir nâri* ('bank of the river'), whence the Arabic name *kibrīt* still current (though it now usually means 'matches' !). Symbols also derived from resemblances in shape, colour, and other properties, as with the circle of the sun to symbolize gold and the crescent of the moon to represent silver. A further origin of symbols lay in the employment of contractions, many of which ultimately became mere conventional signs. Finally there are those numerous early scientific or pseudo-scientific symbols which owed their origin to religious, philosophical, or magical beliefs and practices, or to folk-lore.

In early times, possession of scientific and technical information was confined to comparatively few, and was correspondingly valuable. One of the principal purposes of symbolism was therefore, as Mr Duveen points out, to conceal professional knowledge from the layman. Before technical writings could be interpreted it was necessary for the student to learn a whole language of symbolism, in the process of which he was doubtless assessed by his teachers as to his fitness for the particular craft or profession.

Symbolism, however, had another aspect. Largely owing to Gnostic influence, mystical force was attached to words, letters, and signs, which thus became more than mere representations and were attributed with actively operational functions. This belief led to the widespread custom of wearing amulets, talismans, and engraved gems—such as the abraxas of Basilides (second century A.D.), in which was embodied the number of days in the year as signifying the 365 orders of spirits emanating in succession from the Supreme Being. Gnostic talismans of this and similar kinds were used in all parts of the ancient world—even in Britain, for in 1827 a specimen was unearthed near the Roman fort of Segontium in North Wales.

Symbolism found a further field of application in the doctrine of signatures, which taught that the external characters of plants indicated the diseases for which Nature had intended them as remedies. 'Sin and Satan,' wrote a seventeenth-century naturalist, 'have plunged mankind into an

ocean of infirmities, yet the mercy of God, which is over all His workes, maketh grasse to growe upon the mountains and herbes for the use of men, and hath not only stamped upon them a distinct forme, but also given them particular signatures, whereby a man may read even in legible characters the use of them.' Even John Ray, who expressed some scepticism over the doctrine, believed that 'noxious and malignant plants do, many of them, discover something of their nature by the sad and melancholick visage of their leaves, flowers, or fruit.' The conception lying behind the theory of signatures was the perennially stubborn belief in a real connection between object and image, a belief universally held until the growth of modern science and still not without its superstitious adherents.

We no longer believe that the sigillary marks in the rhizomes of Solomon's Seal (*Polygonatum multiflorum*) indicate that the plant is suitable for curing 'any bruise, black or blue spots, gotten by falls, or women's wilfulness in stumbling upon their hasty husbands' fists'—we relegate such fables to the obscurity they merit. Yet perhaps as we do so an uneasy suspicion is aroused: are we not ourselves inclined to attach too much importance to signs and symbols in science, and to think that when we have found a formula we have explained a phenomenon?

It is a suspicion worth attention, even though the principal object of scientific symbolism is obviously to convey information rather than to obscure it, and to be precise rather than vague. Take the chemical formula $CH_3.COOH$. This to a chemist is an epitome of the chemical behaviour of acetic acid: among other things it tells him that the molecule of acetic acid is sixty times as massive as one-sixteenth of the atom of oxygen, that the acid is an oxidation product of acetaldehyde, that it has one hydrogen atom replaceable by a metal, that it has three hydrogen atoms replaceable by chlorine, that it possesses a sour taste and a comparatively low boiling-point, and that it is miscible with water. The same sort of concentrated factual knowledge is of course to be found in all other chemical formulae, which nowadays constitute an essential factor in the advance of both pure and applied chemistry. It should nevertheless be remembered that a chemical formula, like other formulae used in science, conveys only selected information, and that too complacent a reliance upon symbolism may lead to a mental sclerosis. When the schoolboy heats sulphur with iron filings and neatly rounds off his account of the experiment by writing $Fe + S = FeS$ he feels that he knows all there is to be known about that particular chemical change. *Mutatis mutandis*, older scientists not seldom succumb to the same deceptive euphoria, the aesthetic satisfaction of tidy symbols distracting their attention from problems still unsolved.

The tendency to unwarranted complacency shown by unreflective scientists is most marked when a phenomenon can be described by an elegant mathematical expression, for, in spite of abounding evidence to the contrary, we are all prone to think that the simplest of equally possible explanations must necessarily be the correct one. But, in science at least, mathematical expressions are of the same fundamental character as other signs and symbols; that is, they are concise descriptions and possess no greater authority. As observation grows and experiment extends, the possibility follows of ever closer accuracy in description: Newton's mechanics is subsumed in Einstein's, and the history of science gives us no reason to suppose that Einstein has said the last word. Mathematics affords science a distilled symbolism, but a symbolism nevertheless; the facts it symbolizes and correlates are the product of the laboratory. Yet since mathematics affords the most precise form of description it is for mathematical expression that science should strive. In the words of Sir D'Arcy Wentworth Thompson: 'Not only the movements of the heavenly host must be determined by observation and elucidated by mathematics, but whatsoever else can be expressed by number and defined by natural law. This is the teaching of Plato and Pythagoras, and the message of Greek wisdom to mankind. So the living and the dead, things animate and inanimate, we dwellers in the world and this world wherein we dwell—Πάντα γα μὰν τὰ γιγνωσκόμενα—are bound alike by physical and mathematical law.'

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Chemical properties and structure of the penicillins

E. CHAIN

In spite of difficulties arising from its instability and from the extremely small quantity of material originally available, penicillin (a British discovery) has been more intensively studied by chemists than perhaps any other organic compound whatsoever. Its investigation has opened up completely new fields in the chemistry of heterocyclic compounds. This authoritative article is based upon the chemical reports, nearly seven hundred in all, prepared during the Anglo-American research on penicillin during and since the recent war.

HISTORICAL

In the first paper on penicillin Fleming [1] drew attention to the fact that it was an unstable substance. The instability of penicillin was also emphasized by Clutterbuck, Lovell, and Raistrick [2], who carried out the first chemical investigations on this substance.

The instability of penicillin was undoubtedly the chief reason for the fact that eleven years elapsed between its discovery by Fleming in 1929 and the discovery of its unique chemotherapeutic properties by the Oxford workers [3]. Its instability was one of the main reasons for the decision made by Chain and Florey in 1939 to reinvestigate its properties, for it was anticipated that the study of a substance with such unusual chemical properties would probably lead to interesting biochemical discoveries.

Clutterbuck, Lovell, and Raistrick had shown that penicillin was an acid of low molecular weight which to a large extent could be extracted from the acidified culture medium into ether, but the antibacterial activity of the ether extract was lost on evaporation of the solvent. The Oxford workers [4] showed that the antibacterial activity could be transferred without loss from the ethereal solution into aqueous solution by adding the correct amount of alkali to bring the solution to neutrality. The aqueous solution containing a salt of penicillin could be evaporated to dryness from the frozen state in a vacuum without loss of activity. The dry preparations thus obtained were brown hygroscopic powders which preserved their antibacterial power for long periods if kept dry. These preparations were shown to possess remarkable powers of protecting mice against infections with *Streptococci*, *Staphylococci*, and *Vibrio septique* which would otherwise prove fatal. Later it was demonstrated with purer preparations that penicillin was also extremely effective in combating many of the most important and dangerous infections in man [4].[1]

After the recognition of the remarkable clinical value of penicillin as a chemotherapeutic agent against infectious diseases the elucidation of its chemical structure became a matter of great urgency and importance.

Towards the end of 1942 Dr Wilson Baker (now Professor of Organic Chemistry in the University of Bristol) and Sir Robert Robinson joined Drs Chain and Abraham in the chemical studies on penicillin. This team of workers was responsible for all penicillin degradation studies at Oxford. Dr J. J. Cornforth, and later many other members of the Dyson Perrins laboratory, Oxford, joined in the synthetic studies. Dr E. R. Holiday, of the London Hospital, working in the Department of Biochemistry at Oxford, collaborated on the ultraviolet absorption measurements, and Drs H. W. Thompson and R. E. Richards on investigation of infra-red spectra.

The main handicap to the penicillin degradation studies at Oxford was shortage of material. Most of the work was carried out with preparations made in the small production plant at the Sir William Dunn School of Pathology. The total amount of penicillin available to the Oxford workers was, in terms of pure material, about 1·5–2 gm, but of this only a few hundred milligrams were in the form of highly purified material, whereas the bulk of the work was carried out with material of only 50–60 per cent. purity. Under these circumstances the collaboration of Mrs Dorothy Hodgkin and Mrs B. Rogers-Low of the Department of Crystallography, Oxford, and of Dr C. W. Bunn and others at the laboratory of Imperial Chemical Industries at Winnington, was

[1] For a review of the early work on penicillin see also [6].

of particular value. By means of X-ray crystallographic studies on degradation products of penicillin, physicochemical data were obtained which made possible their identification even when available only in very small amounts. X-ray crystallographic studies on single crystals of the sodium, rubidium, and potassium salts of penicillin have played an important part in the final elucidation of the structure of the penicillin molecule, making possible a conclusive decision between alternative formulae.

Other groups of chemists in England, both academic and industrial, began to take interest in the chemical investigations on penicillin. A group at the Imperial College of Science, London, under the leadership of Dr A. H. Cook and Professor Sir Ian Heilbron, and groups at the firms of Glaxo Laboratories, Burroughs Wellcome Ltd., and Imperial Chemical (Pharmaceuticals) Ltd. started investigations. Later the following groups also participated: Department of Chemistry, Manchester University; Departments of Chemistry and Colloid Science, Cambridge University; National Institute for Medical Research, London; British Drug Houses Ltd.; Boots Pure Drug Company Ltd.; May and Baker Ltd.; and Imperial Chemical Industries Ltd., Alkali Division.

Simultaneously, American chemists began work on the structure of penicillin. The American work was carried out on a very large scale. The following academic, governmental, and industrial laboratories participated in it: Cornell University Medical College, Department of Biochemistry and Russell Sage Institute; Federal Security Agency, Food and Drug Administration; Harvard University, Department of Chemistry; University of Illinois, Department of Chemistry; University of Michigan, Departments of Chemistry and Physics; National Bureau of Standards; Northern Regional Research Laboratory, U.S. Department of Agriculture; Rockefeller Institute for Medical Research at Princeton; Abbott Laboratories; Cutter Laboratories; Heyden Chemical Corporation; Eli Lilly and Co.; Merck and Co. Inc.; Parke, Davis and Co.; Chas. Pfizer and Co. Inc.; Shell Development Company; Squibb Institute for Medical Research; the Upjohn Company; and Winthrop Chemical Company Inc.

In 1943 the governments of Great Britain and the United States imposed a security ban on all information relating to the chemical investigations on penicillin. This ban remained in force until the end of 1945. Soon after its introduction the British chemists engaged in research on penicillin formed a committee of representatives of different groups with a view to exchanging information. Dated reports, known as the 'PEN' series, were sent to the secretary of this committee, and were regarded as equivalent to publications which normally would have been sent to the scientific journals. Most of the British degradation work on penicillin was carried out between May and October, 1943, and is contained in the 'PEN' reports.

The American work on penicillin was at first done independently of the British work. After the imposition of the publication ban on penicillin chemistry the Medical Research Council in Great Britain and the Office of Scientific Research and Development in the United States started negotiations with a view to establishing a regular exchange of information between the American and British groups of chemists. Agreement was reached early in 1944. The Medical Research Council set up the Committee for Penicillin Synthesis, which replaced the unofficial committee mentioned above and to which the British workers now sent their progress reports. These became known as 'CPS' reports. Similarly the American workers sent in monthly reports to the Office of Scientific Research and Development. The British and American reports were circulated among the accredited workers on penicillin chemistry.

The magnitude of the combined Anglo-American effort on penicillin chemistry can be gauged from the fact that nearly 700 reports were received by the American and British Government organizations co-ordinating the chemical work on penicillin.

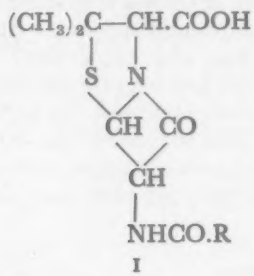
This international collaboration continued until the end of 1945 and proved very fruitful. Though its chief aim, a workable synthesis of the penicillin molecule capable of replacing the fermentation method of production, was not achieved, a great deal of valuable information of great scientific interest was collected. The work embodied in the reports deals with degradation studies, the synthesis of degradation products, model compounds and intermediates for projected penicillin syntheses, and different physico-chemical investigations such as infra-red spectra and X-ray crystallographic investigations. The reports are now open for inspection in various libraries in Great Britain and the United States. A compendium of these reports, in the form of a comprehensive Anglo-American monograph on penicillin chemistry, is in the process of being published by the Princeton University Press under

the auspices of the National Academy of Sciences, Washington, D.C.

In the following pages it is proposed to give a brief account of the main results of the Anglo-American work on the structure of the penicillin molecule. It is not intended to follow strictly the historical course of events, and the number of references will be limited to a minimum. A more detailed account is in course of publication [7].

MULTIPLICITY OF THE PENICILLINS. CHEMICAL AND PHYSICAL PROPERTIES

It became clear at an early stage of the structural investigations that penicillin was not a single substance, but that there existed a number of penicillins having very similar chemical and biological properties but differing in their chemical composition. It was shown that the penicillins possessed a common nucleus but differed in the nature of a side chain. The structural formula for the penicillin molecule at present generally accepted is represented below (I):



I

The penicillins were at first differentiated by Roman numerals or letters, but eventually a nomenclature was adopted according to which they are differentiated by prefixes indicating the nature of the side chain, e.g. benzylpenicillin, in which R = $C_6H_5CH_2$; heptylpenicillin, in which R = C_7H_{15}; and so on. In table I are given the names and empirical formulae for some penicillins isolated from mould culture filtrates.

The penicillins are strong monobasic acids, with a *p*K of about 2·9. There is no indication of the presence of a basic group in the electrotitration curve, and even if the titration is carried out in glacial acetic acid with perchloric acid as titrating acid no sign of a basic group can be detected. This absence of a basic group, even of a very weak type, in the penicillin molecule has been of great significance in structural considerations.

Determination of the molecular weights of the penicillins by different methods showed that they possessed molecular weights corresponding to the simple formulae represented in table I.

Benzyl- and *p*-hydroxybenzylpenicillin show the ultra-violet absorption characteristic of the benzene nucleus, but the penicillins with aliphatic side chains show no characteristic ultra-violet absorption.

In the form of the free acids the penicillins are soluble in ether, chloroform, and esters, and can be extracted from acidified aqueous solutions into these solvents (with the exception of *p*-hydroxybenzylpenicillin, which cannot be extracted with chloroform). In the above-mentioned organic solvents the penicillins are stable for many days at temperatures below 7° C. In aqueous solutions the penicillins are stable only at a *p*H ranging between 5 and 8, i.e. in the form of their salts. In acid or alkaline solutions they rapidly lose their biological activity. The alkali salts of the penicillins crystallize readily. MacPhillamy and Wintersteiner were the first to obtain a penicillin salt in the crystalline state; in July 1943 they crystallized the sodium salt of benzylpenicillin. Apart from the alkali salts no other metal salts of the penicillins have been obtained in the crystalline state, but several crystalline salts with organic cations have been prepared by direct combination of the bases with the free penicillin acids in organic solvents (for example the triethylamine, N-ethylpiperidine, and procaine salts). Under these conditions the salts precipitate from solution. The inactivation of the penicillins in acid or alkaline solutions is accompanied by a change of solubility and acid-base properties. The products of inactivation are *zwitter-ions* possessing two acid groups and one basic group and are insoluble in

TABLE I

Name of Penicillin	*Formula of Side Chain*	*Empirical Formula*
Δ^2-Pentenylpenicillin	$CH_3.CH_2.CH{=}CH.CH_2$—	$C_{14}H_{20}O_4N_2S$
Δ^3-Pentenylpenicillin	$CH_3.CH{=}CH.CH_2.CH_2$—	$C_{14}H_{20}O_4N_2S$
n-Amylpenicillin	$CH_3.CH_2.CH_2.CH_2.CH_2$—	$C_{14}H_{22}O_4N_2S$
n-Heptylpenicillin	$CH_3.(CH_2)_5.CH_2$—	$C_{16}H_{26}O_4N_2S$
Benzylpenicillin	$C_6H_5.CH_2$—	$C_{16}H_{18}O_4N_2S$
p-Hydroxybenzylpenicillin	$HO.C_6H_4.CH_2$—	$C_{16}H_{18}O_5N_2S$

organic solvents. Both have been isolated in the crystalline state. Electrometric titrations showed that the products of acid inactivation differ from those of alkaline inactivation. The former were termed penillic acids; they are isomeric with the penicillins and possess a basic group with a pK of 7·6. The latter were termed penicilloic acids; they are hydrolysis products of the penicillins, containing an additional molecule of water, and possess a basic group with a pK of 5. Both degradation products have played an important part in the elucidation of the structure of the penicillin molecule as a whole. Their structures will be discussed below.

The penicillins lose their biological activity under the influence of many reagents other than acid and alkali. Thus they are inactivated by several metal ions, including zinc, cadmium, lead, mercury, and copper; the action of these metal ions is catalytic. The penicillins are also inactivated by primary alcohols and amines, ketonic reagents such as hydrazine and hydroxylamine, the amino-acid cysteine, and an enzyme, produced by several bacterial species, termed penicillinase.

The penicillins are stable towards reducing agents. The pentenylpenicillins readily react with catalytically activated hydrogen to give amylpenicillin.

All penicillins are stable towards iodine in neutral solution but are rapidly destroyed by bromine. They are destroyed also by oxidizing reagents such as hydrogen peroxide and potassium permanganate.

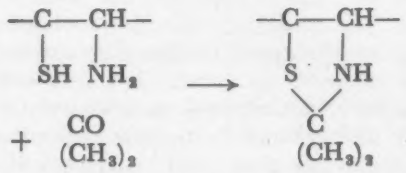
The carboxyl group in the penicillin molecule can be esterified by diazoalkanes, and the methyl and ethyl esters have been obtained crystalline. The methyl ester of benzylpenicillin possesses only weak antibacterial activity *in vitro* but is as active as the alkali salts *in vivo*, presumably because it is hydrolysed by a hydrolytic enzyme in the tissues. An esterase capable of hydrolysing the methyl ester of benzylpenicillin has been found in guinea-pig extracts. It has not been possible to hydrolyse esters of penicillin by chemical means without appreciable losses of activity, even under the mildest conditions.

THE THREE FUNDAMENTAL COMPONENTS OF THE PENICILLIN MOLECULE

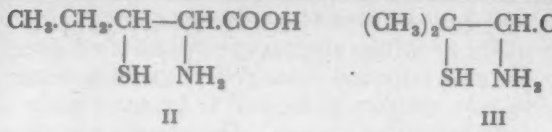
The penicillin molecule is built up of three fundamental components into which it can be broken down with the participation of two molecules of water. These are the thiol-amino-acid β-thiolvaline, also termed penicillamine (which is a constituent common to all penicillins); an acylated aminoacetaldehyde termed penilloaldehyde (the acyl group of which differs in the different penicillins); and one molecule of carbon dioxide.

PENICILLAMINE

This substance was the first degradation product of penicillin to be obtained in the crystalline state [5]. It can be precipitated, in the form of its complex with mercuric chloride, from acid hydrolysates of the penicillins or from solutions of alkali-inactivated penicillins. It can be obtained in the form of its crystalline hydrochloride after decomposition of the mercuric chloride complex with hydrogen sulphide. It has the molecular formula $C_5H_{11}O_2NS$, and is thus the part of the penicillin molecule containing the sulphur atom. It gives strong colour reactions for free —SH with sodium nitroprusside or ferric chloride, and its nitrogen is present as α-amino nitrogen, which can be determined according to the method of van Slyke. When the hydrochloride of penicillamine is dissolved in acetone and the solution is evaporated to dryness a crystalline derivative is obtained which contains no free —SH or $—NH_2$ group and has the molecular composition $C_8H_{15}O_2NS$. On heating with dilute acid, acetone is liberated and the hydrochloride of penicillamine regenerated. This suggested that the —SH and $—NH_2$ groups in penicillamine were next to each other and had reacted with acetone to give a thiazolidine:

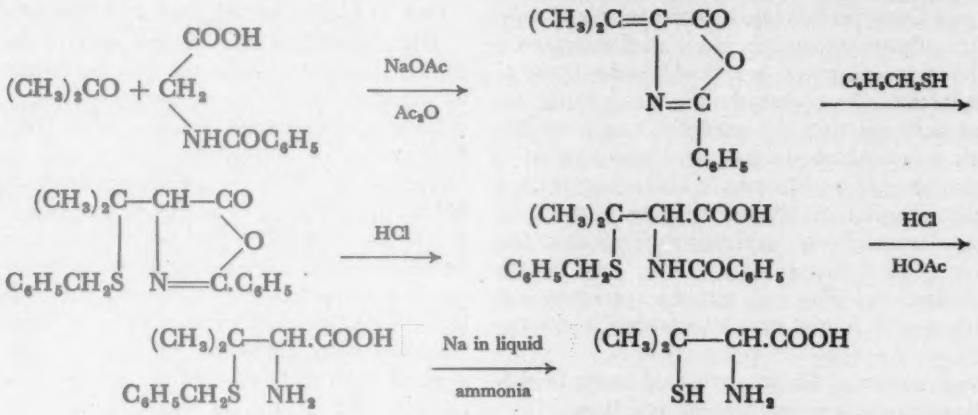


On oxidation with bromine water penicillamine hydrochloride was transformed into a crystalline amino-acid with the molecular formula $C_5H_{11}O_5NS$; this is the corresponding sulphonic acid. The electrometric titration curve of penicillamine showed three titratable centres, with pK values of 1·8, 7·9, and 10·4, corresponding to the carboxyl, amino, and thiol groups respectively. Of the two isomeric formulae possible for penicillamine (II and III), II seemed improbable because C-methyl determinations according to the method of Kuhn and Roth gave values of only a fraction of one molecule. This finding was in agreement with structure III, which contains a *gem*-dimethyl group:



II III

The correctness of structure III for penicillamine was proved by synthesis. The first synthesis of *dl*-penicillamine was achieved at Oxford (Abraham, Baker, Chain, Cornforth, and Robinson, 1943) and consisted in the addition of benzyl mercaptan to 2-phenyl-4-*iso*propylideneoxazolone in the presence of sodium methoxide, following the method of Carter, Stevens, and Ney (1941) for the synthesis of methyl cysteine. The steps involved in the synthesis are indicated by the following scheme:



Later several other methods of synthesis of *dl*-penicillamine were developed. The resolution of *dl*-penicillamine can be achieved by the fractionation of the brucine salt of the N-formyl derivative. Natural penicillamine belongs to the *d*-series. This was first concluded from its optical behaviour and that of its *iso*propylidene derivative, and was finally proved by treatment of the phenylureido derivative with Raney nickel; this led to the phenylureido derivative of *d*-valine (Merck group, October 1943). Penicillamine is another example of an amino-acid possessing the 'unnatural' *d*-configuration occurring in metabolic products of micro-organisms. It will be recalled that the antibacterial polypeptides gramicidin and tyrocidine, and the antigen from *B. mesentericus*, contain amino-acids of the unnatural configuration.

Penicillamine is a new amino-acid which up to the present time has not been found in any other biological material. It is more soluble in water than cysteine and its disulphide is very resistant to reduction. Neither *d*- nor *l*-penicillamine, nor their disulphides, are attacked by enzymes occurring in animal tissues.

THE PENILLOALDEHYDES

While penicillamine is a constituent common to all penicillins, each penicillin gives rise to a different penilloaldehyde. The penilloaldehydes can be obtained in the form of their 2,4-dinitrophenylhydrazones after hydrolysis of the penicillins by dilute acid at 100° C and precipitation of penicillamine with mercuric chloride. They can also be obtained by decomposition with mercuric chloride of the penicilloic acids, which are the products of alkaline inactivation of the penicillins. The first penilloaldehyde to be isolated was derived from Δ^2-pentenylpenicillin, prepared from surface cultures, with which the British investigators had been working. Its structure was established as follows (Oxford workers, September–November 1943). The elementary analysis of the dimedone derivative and determination of its molecular weight by crystallographic X-ray measurements indicated that the molecular formula of the penilloaldehyde was $C_8H_{13}O_2N$. Oxidation with silver oxide gave an acid $C_8H_{13}O_3N$. After hydrolysis with 10 per cent. hydrochloric acid or sodium hydroxide a high proportion of the nitrogen of this acid was present as α-amino nitrogen, reacting in the van Slyke determination. Hence it was concluded that it contained a peptide linkage. Meanwhile American chemists had isolated in the crystalline form the sodium salt of the penicillin with which they had been working, and established its molecular formula as $C_{16}H_{18}O_4N_2S$. The American

penicillin, like the British one, yielded penicillamine on acid hydrolysis. It became known that phenylacetic acid could be isolated from acid hydrolysates of the American penicillin. This easily recognizable substance could never be detected among the hydrolytic breakdown products of the British penicillin, and this fact established conclusively that the two penicillins were chemically different. As both penicillins yielded penicillamine, the difference in their structure could only be located in the penilloaldehyde part of the molecule. On the basis of the molecular formula for the American penicillin it was surmised that it would yield a penilloaldehyde of the formula $C_{10}H_{11}O_2N$ which, on oxidation with silver oxide, would give an acid $C_{10}H_{11}O_3N$. Assuming that this acid contained phenylacetic acid and a peptide linkage, its structure could only be that of phenylacetylglycine, and the structure of the corresponding penilloaldehyde that of phenylacetylaminoacetaldehyde. This being so, it was deduced that the acid deriving from the British penilloaldehyde had the structure of a hexenoylaminoacetaldehyde. This was proved by the isolation of glycine (in the form of its naphthalenesulphonyl derivative) from acid hydrolysates of the acid $C_8H_{13}O_3N$; only a few milligrams were obtained, but the specimen was identified by X-ray crystallographic measurements.

The structure of the hexenoic acid in the British penilloaldehyde was established as follows. The isolation of caproic acid, in the form of its *p*-bromophenyl-phenacyl derivative, from acid hydrolysates of catalytically reduced British penicillin showed that it possessed a straight carbon chain (Imperial College workers, October 1943). The double bond was located in the β-γ-position by oxidation with cold permanganate, which gave propional. Thus the structure of the British penilloaldehyde was that of β-γ-pentenylaminoacetaldehyde. The acetal of this aldehyde was synthesized from aminoacetal and β-γ-hexenoyl chloride. It gives a 2,4-dinitrophenylhydrazone identical with that obtained from the British penicillin. The acetal of the American penilloaldehyde was synthesized in a similar manner from phenylacetyl chloride and aminoacetal.

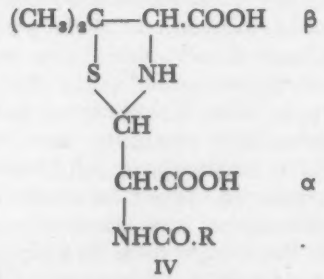
Later, other penilloaldehydes were isolated from natural penicillins, for example *p*-hydroxyphenylacetylaminoacetaldehyde from *p*-hydroxybenzylpenicillin (penicillin X) and *n*-caprylylaminoacetaldehyde from *n*-heptylpenicillin (penicillin K).

THE LABILE CARBOXYL GROUP

The penicillins contain one free carboxyl group and one in bound form. When they are heated in acid solution at 80–100° C for short periods decarboxylation occurs. Decarboxylation also takes place when the products of alkali inactivation are treated with mercuric chloride. When the methyl ester of Δ^2-pentenylpenicillin was treated with mercuric chloride decarboxylation took place and the methyl ester of *d*-penicillamine could be isolated from the reaction product. This showed that the carbon dioxide derived from the bound carboxyl group and not from the free carboxyl group belonging to the penicillamine fragment of the penicillin molecule (I.C.I. workers, 1944).

THE STRUCTURE OF THE PENICILLOATES

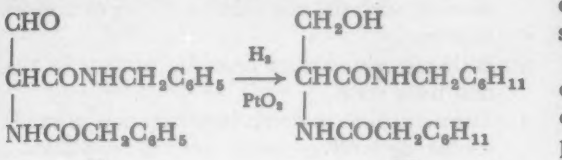
The products of alkali inactivation of the penicillins, termed penicilloates, can be decomposed by mercuric chloride into penicillamine, penilloaldehydes, and carbon dioxide. They contain no free amino or sulphydryl group and give no precipitation with 2,4-dinitrophenylhydrazine before the addition of mercuric chloride. From this it was concluded that penicillamine and the penilloaldehyde were linked together in the penicilloic acid molecule in a thiazolidine ring. The tendency of penicillamine readily to form thiazolidines with aldehydes or ketones had been noticed at an early stage of the investigations (see above), and fission by mercuric chloride is a characteristic reaction of thiazolidines. The most likely position of the labile carboxyl group which appeared as carbon dioxide after treatment of the penicilloates with mercuric chloride was β to the potential aldehyde group of the penilloaldehyde. It was therefore concluded that the penicilloic acids were thiazolidines of the structure IV:



IV

This was proved as follows. It had been found that treatment of the American penicillin with benzylamine led to the formation of a crystalline, biologically inactive, product of the composition

$C_{30}H_{36}N_4O_4S.H_2O$ (Northern Regional Research Laboratory, 1943). Decomposition of this substance with mercuric chloride gave the mercuric chloride complex of penicillamine and the supernatant solution yielded a 2,4-dinitrophenylhydrazone. The structure of the corresponding aldehyde was proved to be V by catalytic reduction with platinum oxide, which gave the cyclohexylamide of N-cyclohexylacetylserine, VI (Merck group, November 1943):

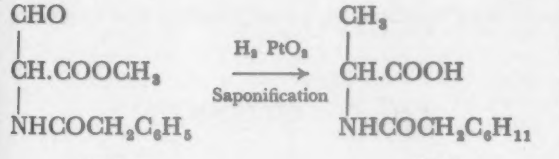


V VI

The aldehydo-acid CHO.CH.COOH which,
NHCO.R

of course, is not stable in the form of the free acid but can be obtained in the form of its esters, amides, or other derivatives, has been termed penaldic acid, and the penaldic acids deriving from different penicillins are differentiated in the same way as the penicillins by prefixes indicating the nature of the group R.

Additional proof for the structure of the penaldic acids and of the penicilloates was obtained by degradation of the product of methanol inactivation of benzylpenicillin. On decomposition with mercuric chloride the methyl ester of an aldehydic acid was liberated which could be converted by catalytic hydrogenation into N-cyclohexylacetylalanine (VIII) and therefore had structure VII:



VII VIII

Thus it was clear that the penicilloates were thiazolidines formed from penicillamine and penaldates. Of the two carboxyl groups of the penicilloic acids the one belonging to penicillamine is termed β, and the other, belonging to penaldic acid, α. With the elucidation of the structure of the penicilloic acids the mechanism of a number of inactivation reactions of the penicillins became clear. As has already been stated, the action of primary amines on the penicillins leads to the formation of α-monoamides of the penicilloates and the action of primary alcohols to the formation of α-monoesters. The latter reaction is catalysed by metal ions, particularly copper, zinc, and tin, and can be greatly retarded by the addition of dimercaptopropanol (British Anti-Lewisite, BAL). In its presence the penicillins are stable in primary alcohols at 37° C for at least 24 hours [8]. The action of metal ions such as copper, zinc, or cadmium on penicillin salts in aqueous solution also leads to the formation of penicilloates. It is thus possible to carry out a stepwise saponification of diesters of the penicilloates.

Penicilloates are also formed from the penicillins under the influence of the enzyme penicillinase. The action of hydrazine on the penicillins leads to the formation of α-hydrazides, that of hydroxylamine to the formation of α-hydroxamic acids; cysteine, which inactivates the penicillins in neutral aqueous solution, reacts with the sulphydryl group (Squibb workers). The α-hydrazides of the penicilloates readily undergo ring closure; 4-phenylacetamino-5-pyrazolone is formed from the α-hydrazide of benzylpenicilloic acid. The action of acetic acid on the penicillins in the form of their free acids leads to the formation of N-acetylpenicilloates (Squibb workers, 1944). The penicilloates deriving from *d*-penicillamine can occur in four stereoisomeric forms, and all of them have been isolated (Merck group, 1944). They differ widely in their melting-points and specific rotations. They are designated as α, β, γ, and δ-forms. The α, β, and γ forms can be isolated from mutarotated synthetic benzylpenicilloates. The δ-form, which is laevorotatory, is obtained by the action of copper sulphate on benzylpenicillin (Squibb workers, 1944).

The penicilloates can readily be synthesized by condensation of penicillamine or its esters with penaldates. Numerous penicilloates and their N-acyl derivatives have been prepared by this method.

THE STRUCTURE OF THE PENILLIC ACIDS AND PENILLAMINES

The products formed when the penicillins are inactivated in aqueous solution at acid *p*H have been termed penillic acids. The first penillic acid to be isolated was derived from Δ^2-pentenylpenicillin obtained from British surface cultures (Duffin and Smith, 1943). The penillic acids have a great power of crystallization. They are insoluble in organic solvents and only slightly soluble in water. They have a higher specific rotation than the penicillins and show a characteristic ultra-violet absorption at about 2,730 A.

Elementary analysis shows that they are isomeric with the penicillins. When treated with mercuric chloride they are decarboxylated and transformed into the hydrochlorides of bases termed penillamines. These are stable substances resisting treatment with hot acid or alkali. They give the colour reaction for a free sulphydryl group but do not possess an α-amino group. Electrometric titration shows three titrable centres, one corresponding to a carboxyl group, one to a basic group, and one to the sulphydryl group. Oxidation with bromine leads to the formation of penicillaminic acid, and on treatment with 2,4-dinitrophenylhydrazine the osazone of glyoxal is obtained. As the sequence of the atoms in the penilloaldehyde moiety is fixed, the only possible structure for the penillamines which will conform with the above facts is the imidazole structure IX (Imperial College workers, 1943). The penillic acids, which contain an additional molecule of carbon dioxide and no free sulphydryl group, were assigned the imidazoline structure X (Oxford workers, 1943). On treatment with cold alkali or on refluxing in methanol the penillic acids undergo isomerization to the *iso*penillic acids. These contain a free sulphydryl group and were assigned the structure XI (Oxford workers, 1944):

The penillamines have also been synthesized by different methods.

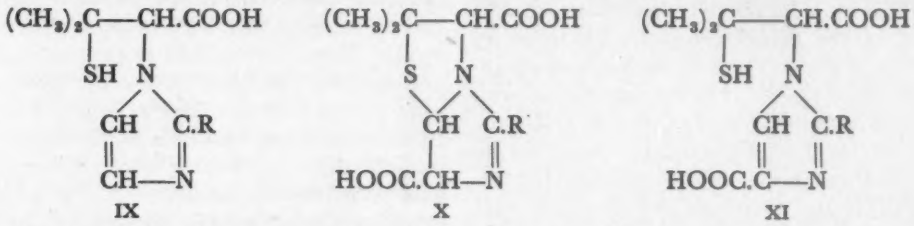
STRUCTURAL FORMULAE FOR THE PENICILLIN MOLECULE

In devising structural formulae for the penicillin molecule the following facts had to be considered:

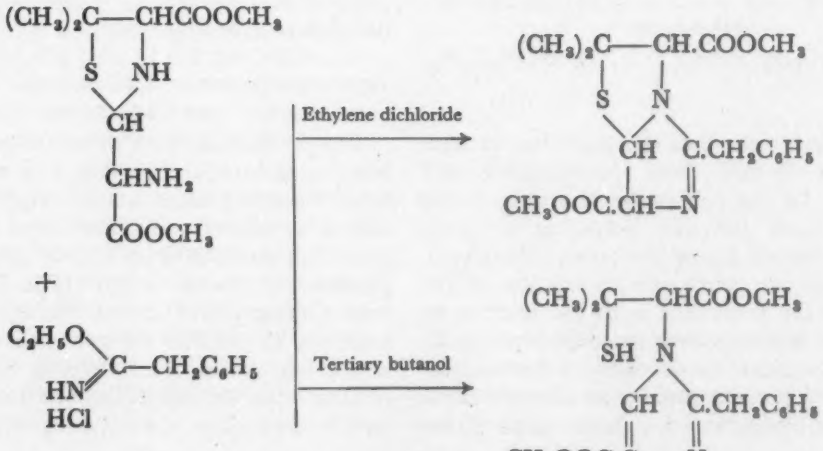
1. The penicillins are built up from penicillamine, penilloaldehydes, and one molecule of carbon dioxide, with the elimination of two molecules of water.
2. Both nitrogen atoms must be present in the non-basic state.
3. The penicillins undergo isomerization to imidazoline derivatives under very mild conditions.

Numerous formulae for the penicillin molecule can be constructed by joining its three components with the elimination of two molecules of water. Many of these possibilities can be discarded because they are in obvious disagreement with the physical and chemical properties of penicillin.

If the penicilloic acids are considered to be formed from the penicillins by direct hydrolysis, without the occurrence of an intramolecular

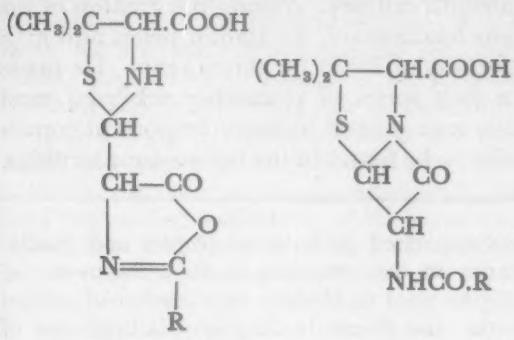


Benzylpenillic acid and benzylisopenillic acid have been synthesized, as outlined in the following schemes (Merck group, 1944):



rearrangement, penicillin formulae can be constructed by eliminating from the penicilloic acids one molecule of water.

The first formulae suggested were the thiazolidine-oxazolone structure XII and the β-lactam structure I (Oxford workers, October 1943):



XII I

The former, containing the reactive oxazolone ring, appeared to explain some of the characteristic reactions of the penicillins, i.e. the reaction with alkali to give penicilloates, the reaction with primary alcohols and amines to give α-esters or α-amides of the penicilloates, and the isomerization to the penillic acids. Its main difficulty lay in the imino group of the thiazolidine ring; this would have been expected to exhibit basic properties, whereas in fact the penicillins did not contain a basic group. The β-lactam structure was suggested in order to overcome this difficulty. In it both nitrogen atoms are present in the form of non-basic groups.

The thiazolidine-oxazolone structure was suggested independently by the Merck group as the most likely expression of the penicillin molecule, though the β-lactam structure was also mentioned by them as a theoretical possibility. It was the structure favoured by the majority of workers until early in 1945. By that time evidence began to accumulate which was difficult to reconcile with it but which was compatible with the β-lactam structure. In order to arrive at a conclusive decision between the two structures investigations were carried out in two directions. On the one hand, model compounds of the different ring systems postulated to be present in the two structures, i.e. thiazolidines, oxazolones, and β-lactams, were synthesized and their properties compared with those of the penicillins. On the other hand, further degradation studies of the penicillins were conducted, and these led to the preparation of several new degradation products. The results of these two lines of work will be considered next.

(*To be concluded*)

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Lazzaro Spallanzani: founder of experimental physiology

E. TORTONESE

Biological inquiries developed rapidly in the eighteenth century. Among the greatest of the scientists responsible for this progress was Lazzaro Spallanzani, an Italian priest and man of science who taught natural history in the University of Pavia for thirty years. He made wide use of the experimental method and in a long series of researches achieved most valuable results, especially in the fields of physiology and general biology. Important contributions to other branches of natural history are also to be found in his voluminous writings.

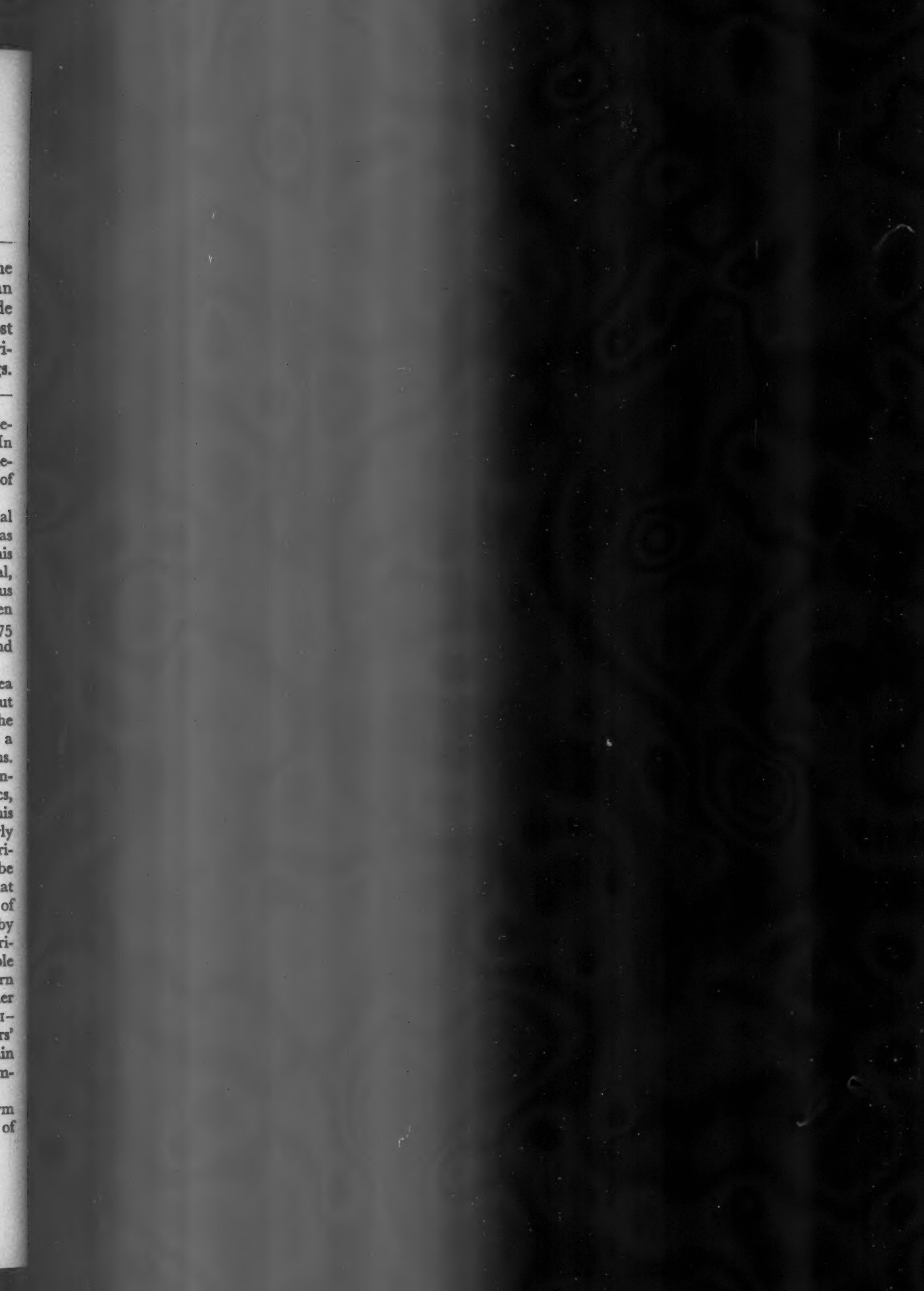
During the eighteenth century great advances were made in various branches of science, thanks to important contributions from several European countries. New fields of inquiry were disclosed, and the foundations were laid for many later achievements. Methods of research were improved, and both experiment and observation became increasingly fruitful. As far as biology is concerned, men of several different nationalities were responsible for the progress accomplished during the century: Linnæus in Sweden, von Haller in Germany, Buffon in France, etc. In Italy, too, several workers, particularly Spallanzani, Cetti, Olivi, and Cestoni, well deserved the title of biologists, though that term was not suggested until three years after Spallanzani's death. The name of Lazzaro Spallanzani (1729–99) will always find a place of honour in the history of science. To him we owe a series of very careful investigations of both the structure and the life-histories of animals. He made also several important observations in various other fields of natural history.

Spallanzani, the son of a jurist, was born at Scandiano, near Modena in northern Italy, on 10th January, 1729. At the age of 15 he was sent to the Jesuit college at Reggio, but soon (1747) went as a student of law to the University of Bologna. Here his cousin Laura Bassi was professor of physics; under her influence and with her help the young man became entirely engaged in scientific studies, in which he felt a deep and increasing interest. His textbooks of law were soon abandoned, while those by Vallisnieri (figure 1) and other naturalists were carefully perused. He was ordained as a priest, and in 1755 came back to Reggio to teach logic in the college there. He had a sound knowledge of classical languages and taught Greek and metaphysics. Two years later he was appointed professor of physics and mathematics in the university in the same town. In 1763 he went to Modena as a teacher of mathematics and Greek in S. Carlo College and of physics and philosophy in the university.

The greater part of Spallanzani's professorial life was, however, spent in Pavia, where he was professor in the university from 1769 until his death on 12th February, 1799. With his arrival, official classes in zoology began in that famous university, to which a new endowment had been given by Queen Maria Theresa. From 1775 onwards the scientific collections, books, and instruments began to be properly arranged.

It is not easy to give briefly an adequate idea of the amount of work done by Spallanzani, but even a short article such as this can show how he contributed to the advancement of science by a series of first-class experiments and observations. He was interested in a variety of subjects and cannot be said to have been a pure biologist: physics, geology, and mineralogy also largely occupied his attention. His name is, however, particularly closely connected with the development of experimental physiology, of which he may rightly be considered the founder. It was in this field that his main discoveries were made. A number of fundamental biological problems were tackled by Spallanzani, who successfully applied the experimental method—the method primarily responsible for the many superb achievements of modern science. He followed the example of another great Italian naturalist, Antonio Vallisnieri (1661–1730), who had strongly advised all 'philosophers' to carry out experiments and observations again and again, and never to tire of collecting and comparing them in order to find out the truth.

In ancient and medieval times there was a firm belief in spontaneous generation or the origin of



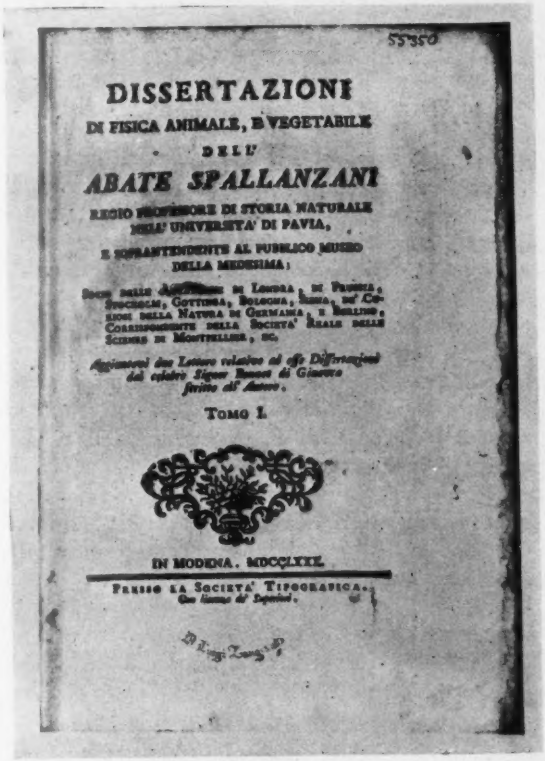
organisms from inanimate material, e.g. by the action of sunshine on mud. A well-known Italian poet, physician, and naturalist, Francesco Redi (1626–96) of Arezzo (Tuscany), showed that the spontaneous generation of insects from dead animals did not occur; if the flesh of the animal were protected, no grubs or maggots appeared in it. Spallanzani made other experiments to disprove the possibility of spontaneous generation (finally disposed of by Pasteur in the following century), and demonstrated that no animalcules developed in vegetable infusions which had been boiled and were kept in properly closed vessels. Infusoria, like other organisms, can develop only from pre-existing individuals of the same kind. This subject is dealt with in his *Essay on Microscopical Observations concerning the System of Generation by Needham and Buffon* (Modena, 1765), which deservedly ranks among his most famous works. Its publication marks a definite victory over such opponents as Needham and Buffon.

It is evident from these researches that the reproductive processes of living things had an outstanding interest for Spallanzani. After close investigations he was able to advance partial explanations of several of them. In his *Prodrome to a Work concerning the Reproduction of Animals* (Modena, 1768), to which great attention was paid by contemporary students, he describes the regenerative power of certain animals.

Several years later (1777–82) he carried out a number of classic experiments on fertilization. Fertilization had been previously attributed to an *aura seminalis* which was responsible for the subsequent development of the eggs. This fanciful idea was accepted even after the discovery of spermatozoa in the seventeenth century (*Animalcula seminalia* were first observed in Holland by Hamm in 1677, and were so named by Leeuwenhoek). Spallanzani showed that fertilization can occur only if the spermatic fluid actually comes into contact with the ovum; he was able to fertilize artificially not only the ova of different amphibians and of the silkworm, but even those of a bitch. He described these achievements in *Prodrome of the New Italian Encyclopaedia* (Siena, 1779). He failed, however, to recognize the spermatozoa as the true activating elements and attributed such a function to the liquid medium. A little more than forty years later Prevost and Dumas (1824) proved that eggs are fertilized by the small cells or animalcules existing in the spermatic fluid and that the latter becomes quite inactive if filtered.

A book (figure 2) which secured continuing fame

FIGURE 1 – *Antonio Vallisnieri, the great Italian naturalist in whose books Spallanzani found an example and an incentive. He was born near Modena in* 1661 *and died at Padua in* 1730.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DISSERTAZIONI

DI FISICA ANIMALE, E VEGETABILE

DELL'

ABATE SPALLANZANI

REGIO PROFESSORE DI STORIA NATURALE NELL' UNIVERSITA' DI PAVIA,

E SOPRAINTENDENTE AL PUBBLICO MUSEO DELLA MEDESIMA;

TOMO I.

IN MODENA. MDCCLXXX.

FIGURE 2 – *Title page of Spallanzani's treatise on animal and vegetable physics.*

FIGURE 3 – *The courtyard of the University of Pavia, with the Spallanzani monument on the left.*

to Spallanzani is entitled *Dissertations on Animal and Vegetable Physics* (Modena, 1780). Its first volume deals with digestion and the second one with reproduction. In both of them several ideas commonly held in that epoch are criticized and modified. It is well known that the history of embryology during the eighteenth century is characterized by the controversy between those who believed in the preformation of the new individual in the germ (preformists), and those who maintained that its formation is completed after fertilization (epigenists). While G. F. Wolff, his great German contemporary, was an epigenist, Spallanzani strongly supported the preformist view. He stated that the embryo is completely formed in the egg and that 'the presence of embryos in females before fertilization is one of the most general laws of nature.' This opinion was strengthened by a series of observations on amphibians, which convinced him that the so-called eggs of frogs are not really eggs at all, but small tadpoles with all their parts already in existence and simply awaiting further development.

The reproduction of plants proved to be another attractive field for research. Spallanzani dealt with it in about a hundred pages of the second volume of the 'Dissertations,' describing what he was able to observe in several species (*Genista*, pea, cucumber, hemp, etc.) and, applying the preformist principle to these organisms also, he maintained that seeds exist before fertilization and that the pollen is a reproductive agent for some kinds of plants, while for others it is unnecessary.

From the six chapters composing the first volume of the book mentioned above it appears that Spallanzani correctly interpreted the process of digestion, about which there had been much controversy. For both Galen and Paracelsus digestion was a 'cooking,' caused by the heat of the stomach, while for Sylvius and van Helmont it was a fermentation. The great French physicist and naturalist R. A. Ferchauld de Réaumur (1683–1757) caused some buzzards to swallow little perforated glass tubes containing small pieces of meat; the perforations were intended to allow the gastric juices to enter the tubes. He then killed the buzzards, extracted the tubes and examined the pieces of meat they had contained. The

appearance of the meat indicated that it had been subjected to a kind of solvent action. This experiment satisfied him that digestion was due to a solvent substance rather than to any mechanical action. Spallanzani agreed with Réaumur and advanced a fuller explanation of the function of the digestive juices. He showed conclusively that the latter are the active agents in digestion, and that their effects are more or less rapid according to the nature of the food ingested. He showed that the juices have antiseptic properties. He stated, too, that the digestive process is quite different from fermentation and that sometimes the alimentary tract exerts an important mechanical action, as, for example, in the gizzards of birds. In 1777 he repeated in public the famous experiments performed in Florence by members of the Accadèmia del Cimento, demonstrating the remarkable strength of hens and ducks, which will in a few hours grind small spheres of glass to powder in their gizzards.

Spallanzani was led to his conclusions by experiments on birds, reptiles, dogs, and other animals, together with an investigation of the digestive process *in vitro*. Some objections against these arguments were raised by J. Hunter, the leading English anatomist and physiologist of his time, but they were easily refuted.

Spallanzani's high qualities as experimentalist are evident also from his work on the circulation of the blood and on respiration. He was the first to observe that in a chick embryo the blood passes from the arteries to the veins through tiny vessels called capillaries. He wrote two papers on the circulation: *On the Action of the Heart on Blood-vessels* (Modena, 1768) and *On the Phenomena of Circulation observed in the Universal Course of Vessels, etc.* (Modena, 1773). In his study of the respiratory process he proved that exchange of gases through the skin (cutaneous respiration) plays an important part in the life of amphibians. He confirmed the hypothesis of the internal respiration of tissues that had been proposed by the mathematician Lagrange of Turin (1736–1813). It was therefore well established that processes of combustion are going on without interruption in every organ and tissue. These subjects are discussed in a posthumous paper, *Memoirs on Respiration* (Milan, 1803).

This brief enumeration of Spallanzani's main achievements in the strictly physiological field is by no means complete, for we are indebted to him for a series of other valuable observations which are primarily of zoological interest. His well-known experiments on the senses of bats, to which reference has already been made in these pages (see ENDEAVOUR, 1947, **6**, 36), are typical. He blinded some of the animals and found that afterwards they could fly in a room and avoid all obstacles, even such slight ones as silken threads stretched across their path. He studied the zoology of sponges, the electrical powers of rays (*Torpedo*) the reproduction of eels, the curious habits of hermit crabs, and the life of some aquatic animalcules (Rotifers, Tardigrads), which can resist desiccation even for long periods.

Spallanzani therefore occupies an important place in the history of zoology. In this connection we must remember his travels, the reports of which were published partly by himself and partly after his death. His journeys greatly widened the field of his observations and enabled him to present many specimens to the museum of the University of Pavia. Both in Italy and abroad he collected

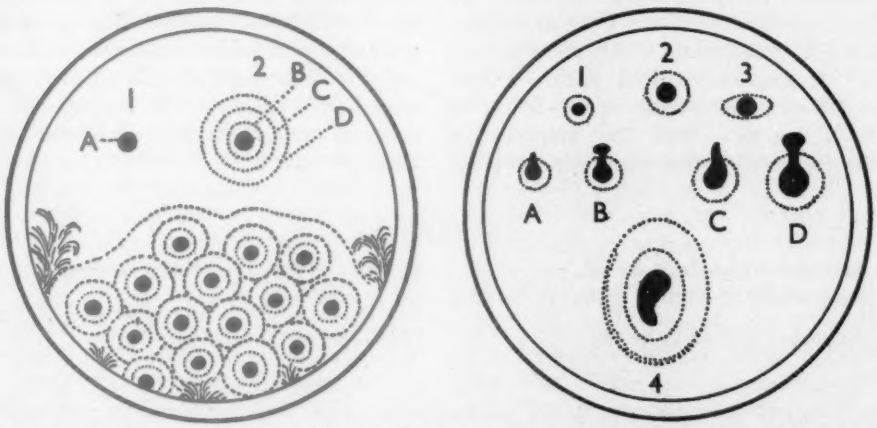

FIGURE 4 – *Frogs' eggs and their early stages of development, as figured by Spallanzani in his 'Dissertations'* (1780).

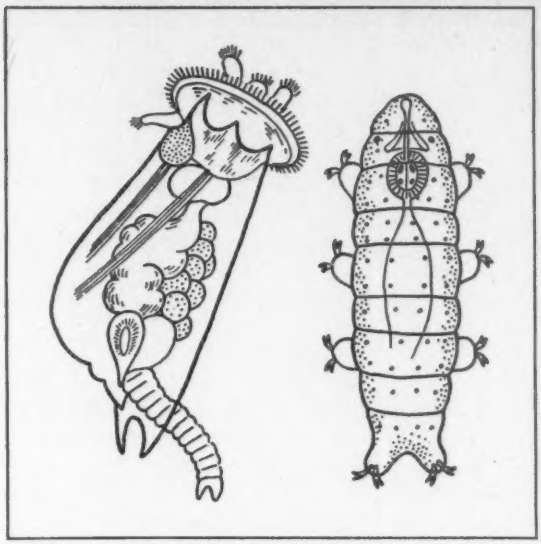

FIGURE 5 – *Small animals whose endurance to desiccation was noticed by Spallanzani: a Rotifer* (Brachionus) (*left*) *and Tardigrad* (Macrobiotus) (*right*). *Tardigrads were so named by him in* 1776 *on account of their slow movements.*

animals as well as minerals and rocks, and he wrote field notes on zoology, mineralogy, and physics. The characteristics of people in various countries and their customs and habits were also noted.

He visited Switzerland (1779) and several parts of the Mediterranean shores (Ligurian, Adriatic, etc. (1781–83)), making valuable observations on marine biology. In 1785 he was invited to go to Padua, where a professor of natural history was needed, but he refused not only because the queen, Maria Theresa, granted him double pay and permission to leave for a journey to Eastern regions, but also because of his genuine affection for Pavia. In 1785 he went to Constantinople, accompanying the ambassador sent there by the republic of Venice, and visited parts of Asia Minor, the Balkans, and Germany; in Vienna he received high honours from the emperor of Austria. His impressions are described in the book *Travel to the East* (Turin, 1788). In another book, *Travels to Sicily and Some Parts of the Apennines* (Pavia, 1792–7), are embodied all the notes collected during a long trip across the Italian peninsula as far as Sicily. Spallanzani climbed Vesuvius and Etna and paid visits to the Campi Flegrei near Naples and Colli Euganei near Padua. His memoirs concern not only mineralogy and geology but also many biological topics, such as the phosphorescence of jelly-fishes, sundry species of birds, the eel-fisheries at Comacchio, and so on.

Unlike many men of science, Spallanzani was a very good writer; his style is not only simple and clear but elegant and convincing, avoiding any rhetorical ornament. He corresponded with the Swiss naturalist Charles Bonnet in Geneva (1720–93), a very keen investigator of living organisms and the discoverer of parthenogenesis in aphids or plant-lice. Bonnet highly appreciated the work of his Italian friend and shared his views on many phenomena, saying that Spallanzani alone had discovered in a few years more than most famous European academies did in many. We owe to Spallanzani a translation of Bonnet's *Contemplations de la Nature* (Modena, 1769), some parts of which are included in his 'Dissertations' together with letters between these two scientists.

Spallanzani was a member of many academies and scientific societies, both Italian (Bologna, Siena) and foreign (London, Stockholm, Berlin, Montpellier). He used to perform all his duties with the utmost keenness and precision. He did not live a secluded life in his laboratory, but was glad to announce in public dissertations the main results of the researches he was carrying on. Spallanzani did not, of course, escape jealousy and slander from his contemporaries, but the quality of his work and his uprightness of character were always a sufficient answer to his critics. In his private and public life and in his scientific work he was never fettered by prejudice and tradition and never failed to reason with an open and unbiased mind.

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Animal camouflage

P. H. T. HARTLEY

The theory that the coloration of animals is of functional and evolutionary significance is now generally accepted, though many extravagant claims once made for it have had to be rejected. Certain patterns of colour may undoubtedly be of value to animals in protecting them from their enemies and allowing them to approach their victims without alarming them. In this article the author discusses and illustrates the main types of animal camouflage.

It is the fate of most scientific theories to pass through three stages of development. When first propounded, a new theory often receives an enthusiastic and rather uncritical welcome. Then, as the exaggerations of some of its more enthusiastic disciples become apparent, there follows a period of hypercriticism, in which the basic idea tends to be rejected because some of the applications suggested are shown to be unsound. Lastly comes a renewed and critical appraisement, from which a sound theory emerges as firmly established within known limits, but an unsound theory vanishes from the scene.

So it has been with the belief that animal coloration is in many cases adapted to protect the wearer, or to aid in ambush and capture of prey. Some of those who followed the pioneer work of the late Sir Edward Poulton put forward suggestions so far-fetched that, along with the patently foolish, much of the more solid theory came to be rejected. In realizing the folly of the suggestion that the colour of the flamingo concealed it during flight across a sunset sky, many zoologists failed to appreciate the perfection with which the plumage of the snipe, *Capella gallinago* (figure 8), conceals the bird in its haunts of tangled marsh herbage, and it was at times asserted that all coloration was a mere by-product of metabolism, without functional or evolutionary significance. Of recent years a sober revaluation of the available facts has shown that animal coloration often serves to conceal or to mislead, and the reality and effectiveness of animal camouflage are not now disputed.

The word camouflage has often been taken as synonymous with protective concealment, but in fact any mechanism which baffles observation by another creature must be regarded as a camouflage device, without reference to the defensive or aggressive nature of its function. Needless to say, the same colouring or structure may often serve a dual purpose, making an animal more difficult for its enemies to discover and its victims to avoid.

A concealing device may be of two kinds. There may be special resemblance to a particular background, such as is shown by phasmids (stick insects, figure 4), leaf insects (*Phyllium pulchrifolium*, figure 3), and tree-frogs (*Hyla arborea*, figure 5), in which main outline, details of structure, basic coloration, and niceties of pattern all contribute to simulation of the habitat of the wearer. Special resemblances are most frequently found in comparatively small and sedentary animals—insects, crabs, and some small weed-haunting fishes—in which a single tree, a patch of tangle, or a mat of floating weed provides a range sufficient for the creatures' needs.

Larger and more active creatures do not usually show special resemblances, for it is clear that the more exactly combinations of structure, pattern, and proportion give resemblance to one kind of background, e.g. a particular leaf, frond, or flower, the wider must be the difference from other backgrounds. The most interesting part of the study of animal concealment is that of the mechanisms by which animals obtain a degree of inconspicuousness in a wide variety of habitats. It is scarcely necessary to say that no scheme of coloration could be suitable for all backgrounds, but the more active forest animals are so patterned that they are inconspicuous in forests and not in one tree of that forest. Similarly the littoral creatures are adapted to the shore in general, and not to the shelter of a particular species of alga.

It should be noticed that it is inconspicuousness, not invisibility, which is required. The function of camouflage is not to prevent the wearer from being seen by its enemy or victim, but to prevent recognition. The mere biochemical processes of vision are unimportant: what must be prevented is the integration of the units of variously illuminated colour, which are the raw materials of perception, into a coherent whole having (to use Dr E. S.

Russell's term) valence for the beholder. It matters not at all that one or many parts of an animal be seen, so long as they are not recognized as belonging to that animal. For example, the long cream streak on *Psammophis subtaeniatus* (figure 6) is in itself conspicuous, but the eye of the beholder tends to follow it and to be diverted from the cylindrical form of the snake itself.

The characteristic outlines of any animal may be concealed by structural alterations or by a pattern which deflects attention from underlying structure. In the comma butterfly *Polygonia c.-album* (figure 7), the outer edges of both fore and hind wings show fretted outlines very different from the usual smooth curves of a butterfly's wings, and it will be noted that, on both the upper and lower surfaces, the patterning follows the jagged outline of the wing's edge. It has been demonstrated that a pattern which is disposed parallel to a boundary tends to reinforce that boundary, while a pattern which ends at a sharp angle to a boundary tends to deflect attention therefrom. It will be seen that at the fore and hind edges of the wings of *Polygonia*, which are of a more normal butterfly outline, the boundaries of the different elements of the pattern are disposed more or less at right angles to the nearest edge.

In the common blenny (*Blennius pholis*, figure 1) the main elements of the pattern are disposed with their boundaries at right angles to the length of the fish. When the blenny is seen against the unnatural background of smooth sand (left lower figure) it is conspicuous enough. But when the fish is seen against the mottled background of a rock (upper figure) it will be realized that the pattern is indeed effective to conceal. The blenny is not invisible, but it is not easily or quickly seen, and as Prof. G. Hale Carpenter emphasized at the 1947 meeting of the British Association, a predator cannot afford to spend too long in search for any one prey. In both the fish and the butterfly it will be observed that the camouflage pattern is made up of strongly contrasting tones rather than of strongly contrasting colours. Tone contrasts—the contrasts between light and dark—are effective at much greater distances than colour contrasts, and it is tone contrast which is used to deflect the attention of the observer from the underlying structure. In *Polygonia* the proximal colour areas of the wings are darker just where they meet the pale distal colour patches, and in *Psammophis* the cream line is emphasized by a darker streak lying immediately alongside it. A sharp contrast of tone, such as is seen in the four pale streaks down the back of a snipe (figure 8), produces the illusion that the pale areas are raised above the darker areas, and so masks the actual structural continuity. The abrupt termination of the pale streaks also helps to deflect attention from the structural boundaries. Patterns which tend to deflect attention from the outlines of the object which bears them are called disruptive patterns.

It is notable that in many animals the details of the pattern are scarcely visible at the ranges at which the coloration is effective for concealment. Dark and light shades merge into a single tone, just as the elements of colour, high-light, and shadow of the background mingle into a single resultant colour and shade. None the less, camouflage by use of a single merging tone is rarely or never attempted when the pattern is to be effective in a background of small diversities. Lights and darks are placed in close contiguity, and the combination of tone and colour which is perceived when they are viewed at a little distance has a luminosity which cannot be attained by a single flat shade.

Colour and tone which fit the general shade of the background are not sufficient to conceal a solid body when, as in the open air, illumination is not uniform. The appearance of solidity, which results from high-lights on surfaces upon which the illumination falls and shade on those surfaces from which light is excluded by the object's own bulk, is always sufficient to make an object stand out in relief, though in other ways it may match its background well. Countershading, the device by which the effects of top-lighting are minimized, is found in many different animal groups—in mammals, in birds, in fishes and reptiles, and in many caterpillars. The effect is to make an object which is actually cylindrical or subcylindrical in shape appear flat—and so once more to delay or prevent, not perception of the object, but its recognition. The comparatively unsubstantial appearance of the young pike (*Esox lucius*) shown in figure 2 illustrates countershading in action.

The device of countershading is an extremely simple one. The dorsal surface, on which the greatest illumination normally falls, is very dark in tone, often nearly black along the middle line. The ventral surface, on which no light normally falls, is white or silvery, and the flanks show a gradation from the dark tones of the back to the pallor of the under side. The effect of such a patterning is easy to understand. The high-lights along the back are counteracted by the dark tones

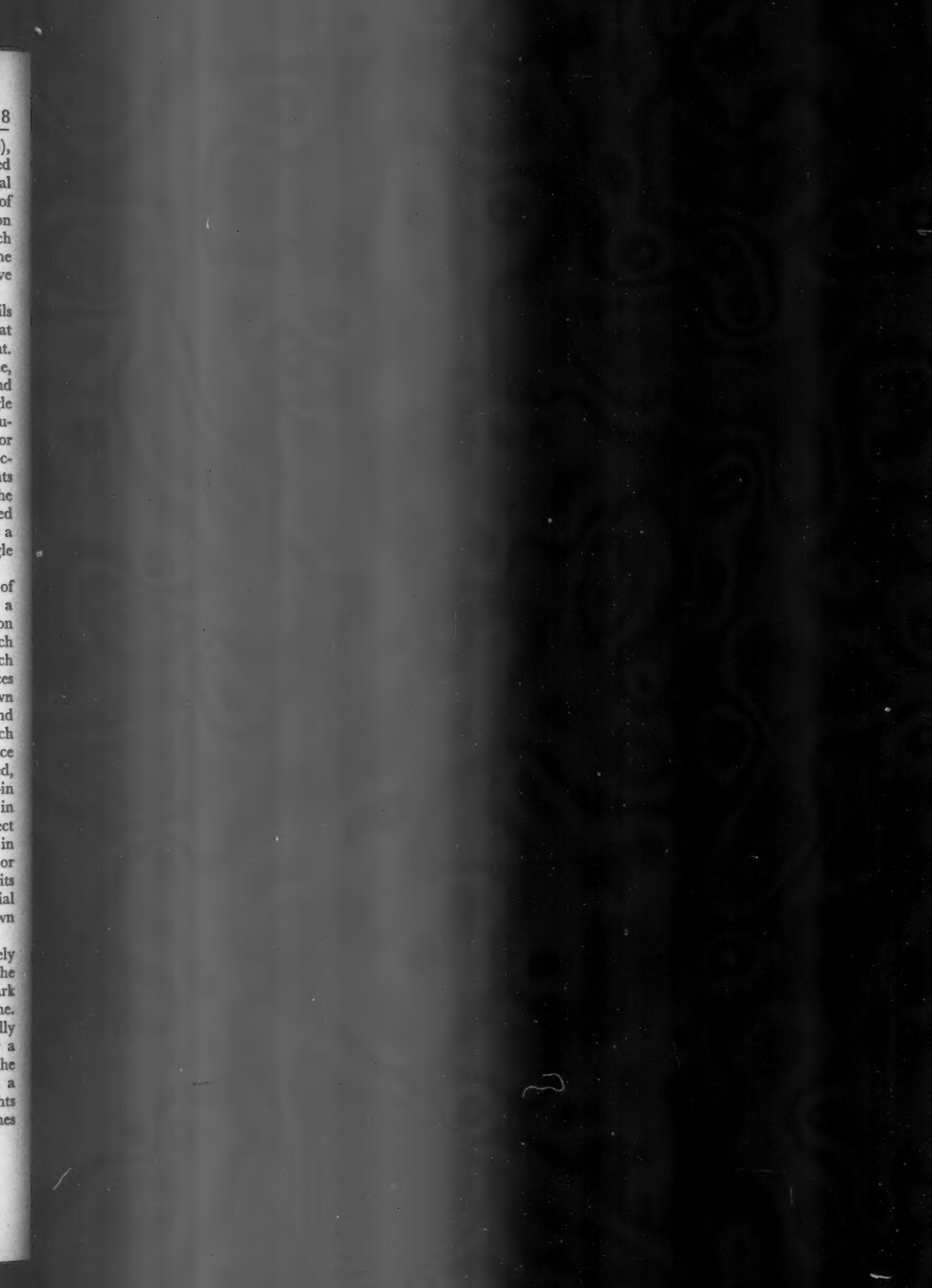

FIGURE 1 – *The common blenny* (Blennius pholis). *A group of three common blennies, showing the combination of disruptive patterning and countershading.*

FIGURE 2 – *The pike* (Esox lucius). *The young pike shows the reduction of shadow on the under surface which results from a countershaded pattern.*

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FIGURE 3 – *A leaf insect* (Phyllium pulchrifolium). *This illustrates special protective resemblance of an insect to leaves.*

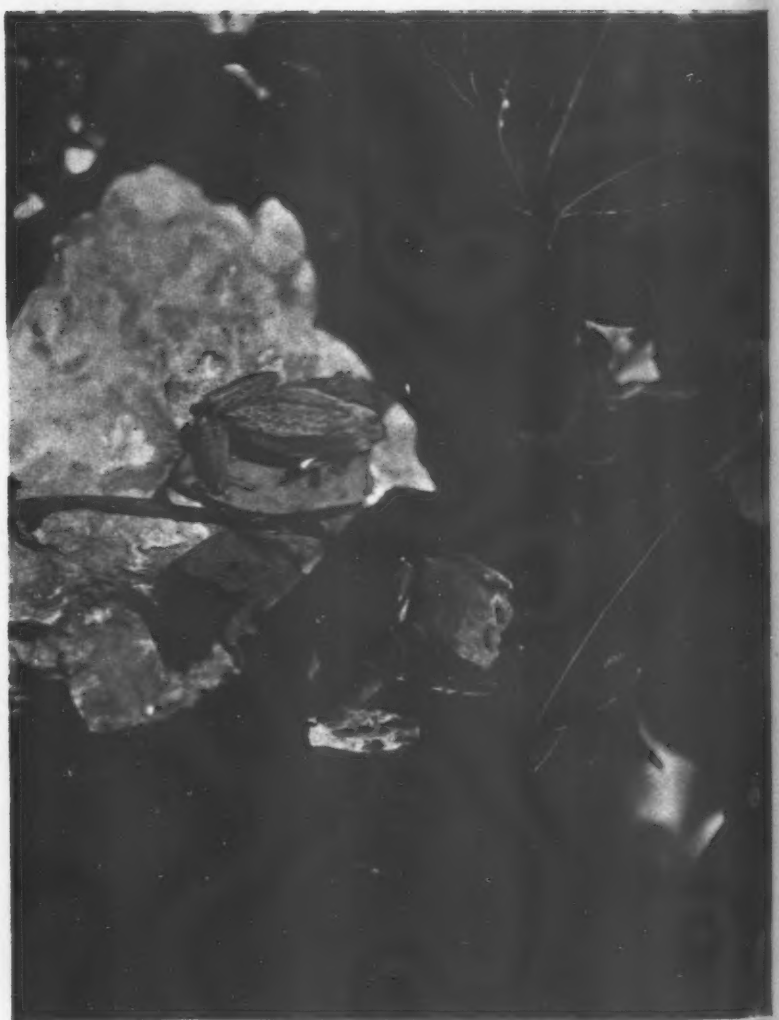

FIGURE 5 – *The tree frog* (Hyla arborea). *Illustrating special protective resemblance of a vertebrate to leaves.*

FIGURE 4 – *Stick insects* (Phasmidae). *Illustrating special protective resemblance of insects to twigs.*

FIGURE 6 – *The long line snake* (Psammophis subtaeniatus). *Illustrating the use of a patch of light colour to deflect attention from underlying structure.*

FIGURE 7 – *The comma butterfly* (Polygonia c.-album). *The upper and under surfaces of the wings of the comma butterfly show the pattern following the irregular edges and at a sharp angle to the smooth edges.*

(Photograph by S. Beaufoy. Reproduced from Butterflies, *by E. B. Ford, by permission of Wm. Collins and Adprint Ltd.)*

FIGURE 8 – *The common snipe* (Capella gallinago). *The snipe on its nest shows coloration adapted to give concealment in marsh country combined with the disruptive effect of pale streaks along the back.*

(Reproduced from Birds in Colour, *by Walter E. Higham, by permission of Wm. Collins and Adprint Ltd.)*

there found. The shadow along the belly is less dense, in that it lies upon a pale surface; the graded shadows on the flanks are also made the less obvious by the tone variation of the surface on which the gradation falls. In the blenny on the sand in figure 1 the belly does not appear perceptibly darker in tone than the back, even though there is strong top-lighting. Countershading, here combined with a disruptive pattern, is sufficient to give a curved surface the appearance of being more or less in one plane.

In a few animals which habitually live belly upwards—the larvae of the eyed hawk moth, *Smerinthus ocellatus*, and one of the Nile catfishes, *Synodontis batensoda*—the coloration exhibits a countershading but the dark tones are on the belly (the illuminated surface). Stronger argument could scarcely be needed for the adaptive significance of countershading, but there is, in addition, experimental evidence of the potency of the appearance of solidity as a factor in recognition. Nice and Ter Pelwyk ('The Auk,' 38, 195–214, 1941) have shown that a cardboard outline of an owl is not a source of alarm to young song sparrows, *Melospiza melodia*, unless it be so tinted as to give an appearance of relief.

It may here be mentioned that some animals which are possessed of peculiarly powerful weapons (the skunks, for example) have a coloration which shows the very reverse of countershading, being light or white above and dark below. Such species have no need of concealment, but rather reap biological advantage from flaunting the banner *nemo me impune lacessit*. An entertaining form of animal camouflage is that which is known to zoologists as Batesian mimicry. In this form of deception, a rare and palatable animal mimics the coloration of a common and unpalatable one: the pattern of the unpalatable model is of the warning type, and makes it easy rather than difficult to see, and the mimicking species departs from the normal coloration of its group to participate in the advantages of this warning. Clearly Batesian mimics must always be much less numerous than the individuals they imitate, for there is some evidence that young animals learn to avoid unpalatable foods by trial and error, at least in part, and the gaudy warning coloration will be of no value unless most of the animals which bear it are, in fact, nauseous.

In many cases the animal which bears a pattern suitable to concealment in a particular habitat must do more than show suitable colours and tones laid on in patterns which tend to deflect attention from its own structural outlines, and to assimilation with the background. In addition to this, the behaviour of the animal must be adapted in order fully to exploit the deceptive possibilities of its pattern. Bitterns (*Botaurus stellaris*) stretch neck and bill upward in order that the longitudinal streakings of throat and breast may repeat the vertically disposed lights and shades of the reed-beds in which they hide. Young pied shrikes (*Hemipus picatus leggei*) in the nest crouch motionless with beaks upstretched, resembling, in their mottled down, a snag upon the branch (W. W. A. Phillips, 'Ibis,' xiv, 5, 450–4, 1940).

An objection which has frequently been raised to theories of the concealing function of animal coloration is that the creature must remain motionless if its pattern is to be effective. At best this is only partly true—a brilliant yellow brimstone butterfly, *Gonopteryx rhamni*, is more obvious in a March woodland than the small tortoiseshell *Aglaia urticae*, which flies at the same time. But even if it were true that all moving animals were equally visible, the objection is still no more than frivolous, for pattern has been evolved in order that the animal may be protected in the periods when it is compelled to remain in one place.

Some of the most perfect examples of the combination of pattern and behaviour to give the greatest camouflage effect are to be found among the geometrid moths. In several species, for example *Eucosmia certata* and *Hybernia leucophaearia* (H. B. Cott, *Adaptive Coloration in Animals*, London, 1940), the wings bear a pattern in which linear elements are dominant, and these elements are so disposed that when the moth is at rest they are at right angles to the long axis of the body. In moths which are so patterned the usual resting position is with the body horizontal, a pose which brings the dominant lines of the pattern upon the wings into line with the vertical cracks and indentations of the bark of the trees on which the moths usually rest. Any other pose would place the pattern on the wings across the directional trend of the pattern of the background and make the moth a relatively conspicuous object. It has been shown by Cott (*op. cit.*) that the African hawk moth, *Xanthopan morgani*, has the pattern upon the closed wings disposed parallel to the long axis of the body; this moth habitually rests with the body vertical and not horizontal. *Xanthopan* thus brings the cryptic pattern into correct alignment with the vertical cracks in the bark of the casuarinas on which it rests. The behaviour is different from that of the geometrids, but the result is the same.

Scientific methods in the conservation of pictures

IAN RAWLINS

Some two years ago considerable publicity was given in the newspapers to the question of the cleaning of certain pictures at the National Gallery, London. A committee of inquiry was appointed which in due course issued a detailed report. The aim of the present article is somewhat different, in that its purpose is to submit a factual review of the scientific and technical methods used in the course of the inquiry. All the cleaned pictures were undamaged.

During the summer of 1947 a committee of confidential inquiry was appointed by the Board of Trustees of the National Gallery, London, to undertake 'a critical review of methods and materials used in the Gallery in procedures of cleaning the pictures . . .' In the course of a few weeks the committee's deliberations and findings were laid before the Board, and subsequently copies of the report (now known as the Weaver Report) became available for consultation by the public. The members of the committee were as follows: Dr J. R. H. Weaver, President of Trinity College, Oxford (chairman); Mr G. L. Stout, Head of the Department of Conservation and Research, Fogg Art Museum, University of Harvard, U.S.A. (now Director of the Worcester, Mass., Art Gallery); and Dr P. Coremans, Head of the Central Laboratory of the Belgian National Museums. Dr Weaver has already written a summary of the main contents and the conclusions reached (see *The Times*, 8th May, 1948).

It should be realized that the application of physical, chemical, and microchemical tests to paintings of supreme value and importance is of necessity limited, especially in an investigation of the kind about to be described, since no appreciable amount of experiment could be conducted upon 'models.' The masterpieces themselves were said to have suffered damage, and consequently upon them, and upon them alone, had scrutiny to be focused if really significant data were to be forthcoming. This being so, physics played a somewhat greater part in the investigation than chemistry, as might be expected from general considerations of non-destructive testing.

Ten pictures were presented to the committee for investigation, one each by Constable, Koninck, Rembrandt, and Velazquez, and six by Rubens. The treatment of seven had been the subject of criticism in the press, and to them attention was more particularly directed. In this article we shall describe in some detail the laboratory work involved in the inquiry, selecting a few of the most crucial observations and the deductions made from them. It is not intended to produce a report subject by subject, but to demonstrate the methods employed as a whole, with characteristic illustrations from among many (about 130) to reinforce the description.

The committee has given to the world of curatorship a document of unique value, and to all lovers of art a model of objective survey in a most difficult field. The scientist will recognize techniques, seldom employed together, co-ordinated here for a common purpose.

To grasp the problem of cleaning, one must have some knowledge of picture-mechanics. This is a comparatively new subject, which sets out to study all the stresses and strains (from whatever cause) to which a painting, conceived as a system of closely associated layers, is exposed. Looked upon in this way, cleaning is seen to be but one facet—though a most important one—of the whole discipline commonly called conservation. The layer-like structure is essentially a fourfold manifold comprising (i) the support, (ii) the ground, (iii) the paint film, and (iv) the surface film. Conservation relates to all of these, whereas 'cleaning' is usually taken to denote the removal of old surface films and their replacement by a new one. The plural is used intentionally, for it is not uncommon to find the remains of several such coatings, fragments of the earliest one locked into the interstices of the design, namely the paint film itself.

Aesthetics apart, a heavily discoloured resinous film is removed because, on account of its shrinkage with time, it is a threat to the continued existence of the paint film below. The contractile forces

PLATE I – *Photograph on panchromatic film of the picture the 'Woman Bathing,' by Rembrandt, before cleaning.*

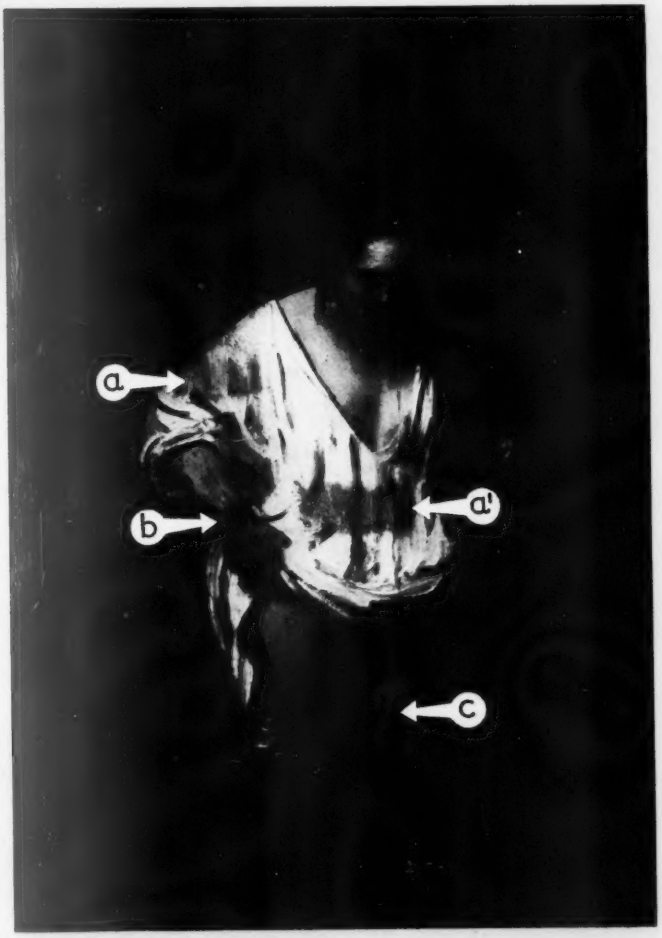

PLATE II – *The 'Woman Bathing,' photographed in filtered ultra-violet light during the cleaning of* 1946. *Previous surface coatings of darkened varnish are visible at* (*a*) *and* (a^1). *Characteristic lack of fluorescence is displayed by overpaint at* (*b*) *and* (*c*).

PLATE III – *An X-ray photograph of the 'Woman Bathing,' taken in 1927, showing the condition of the original paint. An old crack can be seen at (a). An uneven dragging of the paint during its original application is exposed at (b).*

PLATE IV – *This photograph of the 'Woman Bathing,' taken early in 1947, after cleaning, illustrates the stratigraphy of the picture. Priming can be seen at (b^1), and the flow of the paint at (b^2).* (× 4)

PLATE V – *Photograph of 'Le Chapeau de Paille,' by Rubens, before cleaning. At (a) is a vertical split: thin paint makes the ground visible at (b).*

PLATE VI – *Photograph of 'Le Chapeau de Paille' by infra-red radiation. This shows evidence of an old paint layer, blue over green at (a), blue with no green beneath at (b), greenish grey on both blue and green at (c), the undermodelling of the proper left hand at (d), and of the fingers of the proper right hand and sleeve at (e).*

PLATE VII – *This illustration shows the capacity of the microscope, using peripheral illumination, to bring out the depth relations in the paint film.* (× 35)

may be, and often are, sufficient to drag particles of paint away from their moorings, and if this tension is not arrested, the paint film literally falls to pieces. This is an example of picture-mechanics in a localized form, entirely different from the expansion and contraction of the support, which brings about flaking and blistering.

It will be seen at once that the suggestion that old, discoloured varnish films might be bleached is of interest, but in the present context irrelevant. Heavy surface coatings are removed not primarily because of their partial opacity and chromatic distortion, but because they endanger the stability of the strata below. To get rid of them is essential if the picture is to survive. Research might well be directed to discovering a varnish which, on ageing, did not contract (and darken), or if it did was capable of having its elasticity and resilience restored. In the language of chemical physics, this probably implies the complete reorientation of the three-dimensional girder structure which we believe these films to possess. It is not yet known whether the rigidity (a clamping down on the paint film below) occurs at the 'hinges,' or whether the intermolecular bonds tend to shorten, and so grip the paint film like a vice. At present all we can do is to dissolve away the surface film—usually with acetone—and substitute for it a preparation of mastic which will probably remain efficacious and fairly innocuous for about fifty years, when it, in its turn, should be taken off and replaced by a fresh coating. Mastic is the best protective coating yet devised, on account of its ready solubility in a solvent which is harmless to the paint below.

Michael Faraday knew that certain media in which pigment particles are embedded contain a small quantity of resin. When this occurs, great caution in cleaning is demanded, since solvent action at the surface might continue beyond the varnish–paint interface, with disastrous results. Fortunately, however, the solubility of dried oil films in organic solvents is much reduced by the presence of pigment, and thus the safety factor is greater than in industrial tests in which the action of organic solvents upon linoxyn films has been fully examined when the pigment phase was absent.

Generally speaking, so far as safety allows, it is well to remove all traces of old and decayed varnish, since small remnants are not only disfiguring but may be the cause of complex swelling or imbibition, thus disrupting the paint by change of volume. The presence of resinous bodies is clearly revealed in filtered ultra-violet light at all stages of cleaning by their characteristic milky fluorescence. This type of control has become a matter of routine in the National Gallery laboratory. It will be seen that picture-mechanics thus denotes much more than the gross shrinking and swelling to which colloidal substances like wood and other cellulosic aggregates are prone: it includes microscopical reactions taking place between particles and phases in the various picture layers.

With the main features of a painting's anatomy now fresh in mind, it is possible to explain the uses in the laboratory of the various electromagnetic radiations and to illustrate their use upon two specific examples from among the ten pictures already mentioned. These are the 'Woman Bathing' by Rembrandt (1606–69), N.G. No. 54, and 'Le Chapeau de Paille' by Rubens (1577–1640), N.G. No. 852. These two have been chosen partly on account of their importance in the national collection, but more especially because they show the power of optical methods to support our knowledge of picture structure and its modification in the course of history.

Plate I is a panchromatic photograph of the whole picture (No. 54). It was taken in May 1945, more than a year before cleaning. The paint film is a rich oil mixture; the upper layers are more lean, and upon them rich glazes are superposed. Plate II shows the picture under filtered ultra-violet light, during the cleaning in 1946. Former surface coatings of darkened varnish are visible at *a* and a^1. Characteristic lack of fluorescence is displayed by overpaint at *b* and *c*. An X-radiograph, taken as long ago as 1927, shows the condition of the original paint (plate III). An old crack is observed at *a*. An uneven dragging of the paint during its original application is exposed at *b*. Plate IV and figure 1, taken early in 1947, are examples of the stratigraphy or three-dimensional study of the same subject. The former, a macrograph (× 4), shows the proper right hand and wrist after cleaning. Under the flesh colour is seen the priming (b^1). This modest degree of enlargement depicts the fluid character or flow (a rheological feature) of the original paint on the wrist (b^2). These low-magnification images have been found of increasing value throughout, both in the present inquiry and in normal routine.

Figure 1 represents selected (idealized) sections of the phases illustrated in plate IV. Reading from the top downwards, *a* is a cut along the line of a brush-stroke, showing the elliptic edge caused by the surface tension γ of the fluid medium. The relation between γ, the depth *d*, the width *w* of a

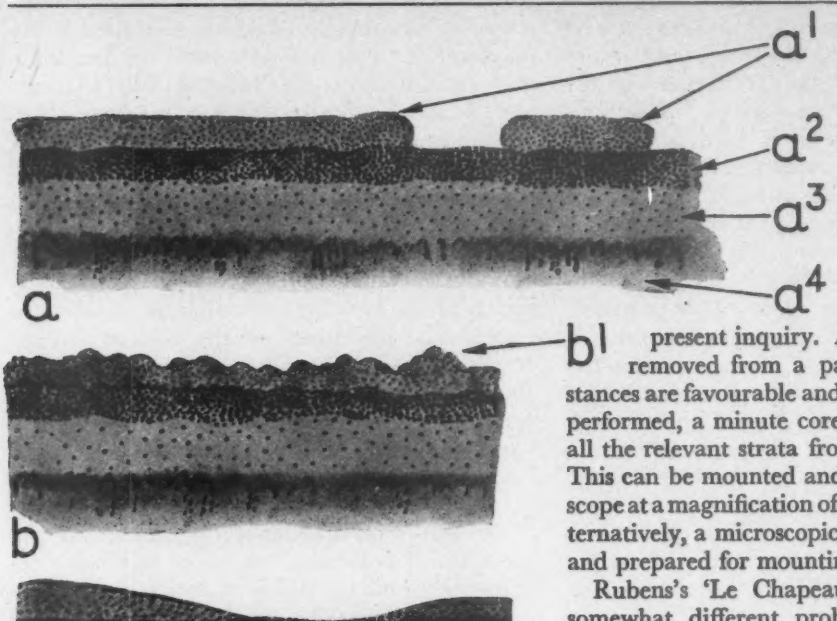

FIGURE 1 – *Diagram showing selected sections of the phases illustrated in Plate IV.*

brush-stroke, and the yield value f of the paint is of the form $\gamma = w^2 f/8d$. The depth d is a measure of the levelling quality, and is sensitive to thixotropic[1] influences, but, other factors being equal, it varies inversely as the surface tension. The drying of paint is a surface effect, not a bulk one, which makes transformations very difficult to follow. To return to the diagram, a^2 is the underpaint, a^3 the ground, and a^4 the wood of the support—in this case probably oak.

Figure 1 (b) is a section across a brush-stroke, displaying the indentations made by the hairs of the brush (b^1). If attrition or erosion has occurred, the gradual slope down (c) to a 'valley' is entirely different from a. At d is seen how the brush-strokes would be smoothed off; the little ridges disappear.

In certain instances it is possible to realize all of these conditions physically, though this was not thought necessary or desirable in the present inquiry. A microscopic portion is removed from a painting, and, if circumstances are favourable and the operation is skilfully performed, a minute core is obtained, containing all the relevant strata from the ground upwards. This can be mounted and viewed under a microscope at a magnification of about 200 diameters. Alternatively, a microscopic section can be detached and prepared for mounting with a microtome.

Rubens's 'Le Chapeau de Paille' presents a somewhat different problem. The picture was cleaned in the summer of 1946. The paint is glaze-like in structure. An X-radiograph made after cleaning revealed the density in the region near the proper right hand. Here the *photographic* density of the (lower) glaze layer is 1·4, and of the (upper) granular paint layer 1·1, proving that the glazes have been left undisturbed.

Plate V shows the portrait before cleaning, whereas plate VI is by infra-red radiation and shows evidence of an old paint layer, blue over green at a, blue with no under-green at b, greenish grey on both blue and green at c, the under-modelling of the proper left hand at d, and the fingers of the proper right hand and sleeve at e.

The capacity of the microscope, using peripheral illumination, to bring out the depth-relations is seen in plate VII. The positions are indicated in the photograph at the top: a and b are photomicrographs at a magnification of × 35, whereas on the right are diagrammatic forms of the corresponding strata. At a the green-grey layer is in focus, and the blue out of focus; at b (left) the lower green is in focus, while at b (right) the top blue is in focus. In these cases the true difference in vertical depth, after allowing for the refractive index of the medium, is of the order of 0·02 mm. These observations have led to a more profound understanding of the master's technique, and the suggestion that the original background had been removed by cleaning is untenable.

[1] Thixotropy is the property of certain gels of liquefying when shaken and resetting on standing.

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The bacteriology of lakes

CHARLES B. TAYLOR

Although certain aspects of the bacteriology of fresh water have been closely investigated because of their importance in relation to public health, the fundamental principles have not received the attention they deserve. The foundations of the subject were laid by the British pioneer Percy Frankland in the latter part of the nineteenth century, but, as Dr Taylor remarks, it is only recently that interest has been revived in problems relating to the multiplication of bacteria in water, their metabolism, and their relationship to other organisms.

As long ago as 1871 Burdon Sanderson showed, by the use of flasks containing sterilized Pasteur's solution, that unfiltered water, ice-water from the purest ice, and even distilled water, contained bacteria. A few years later, following Koch's development of a gelatine medium for the growth of bacteria and the now universal method for their enumeration, a considerable number of research workers devoted their energies to studies of the presence and growth of bacteria in water. Outstanding among these pioneers in Britain was Percy Frankland, whose classical book (1894) well demonstrates that such studies covered a wide field of both applied and fundamental research. During the past fifty years, however, increasing knowledge and appreciation of the dangers of water pollution have to a great extent limited the bacteriological investigation of water to routine tests determining the degree of contamination with human or animal excreta. In the early nineteenth century the potability of water, if investigated at all, was usually assessed on the grounds of the content of organic matter. The work of Frankland and his contemporaries laid the foundations of modern sensitive bacteriological methods to detect faecal pollution, and put existing chemical tests into a secondary role. Much recent work has been directed to the development of improved or more delicate tests, and to attempts—as yet unsuccessful—to differentiate between human, mammalian, and avian types of *Bacterium coli*, an organism which is present in large numbers in excreta and is therefore indicative of faecal contamination. Concentration of effort upon the practical problems of water pollution has resulted in a neglect of investigations of the fundamental principles underlying the actual multiplication of bacteria in water, their biochemical activities, and the part they play in maintaining other forms of life in fresh waters.

FIGURE 1 – *Percy Frankland.*

Most modern systems of water-supply either include a reservoir used for storage or take advantage of a natural lake. In considering the bacteriology of water it is immaterial whether the water is contained in natural or in constructed basins, for the general conditions are similar in each. A lake is not merely a gigantic bottle of water but is an intricate system in which complex biotic, physical, and chemical factors vary considerably. In the course of time the productivity of a lake invariably tends to increase, owing to the constant replenishment of nutrients by the inflowing rivers. Little is known in detail of the part that bacteria play in such aqueous systems, or of the biochemical changes they effect in the water before it passes to the consumer or to the sea. There are three distinct but overlapping spheres of bacterial activity in any large body of water: first, the water free from animal or plant life; second, the water containing plankton, comprising both plant and animal forms; last, the mud or other deposits at the

FIGURE 2 – *Derwentwater, looking towards Borrowdale. A shallow lake (maximum depth* 26 *metres), in surroundings typical of many of the lakes of the English Lake District.*

FIGURE 3 – *Derwentwater, looking north and showing Skiddaw. Reed growth, including* Phragmites, *in foreground.*

FIGURE 4 – *Rydal Water. View taken at south end near the outflow (river Rothay). This is a small, shallow lake with a maximum depth of* 16 *metres flowing into Windermere. Encroachment of rushes, reeds, and water lilies shown in foreground.*

bottom of the lake. The system of water/plankton/mud is not sharply defined, owing to complex movements of the lake water set up by action of the wind and radiation from the sun.

During the winter months, unless there is an ice cover, there is normally sufficient wind to keep the water of a lake circulating freely, thus ensuring even distribution of temperature throughout the water mass, and to maintain saturation with dissolved oxygen (figure 5). Such a system allows oxidation processes to occur in the surface of the mud, and the products of decomposition are carried away to the waters above and become available again to the plankton and bacteria. During the winter, however, low temperatures inevitably restrict the intensity of bacterial activity. During early summer the temperature of the surface water of a lake rises owing to increased solar radiation, and the resulting difference in density of the water gives rise to the formation of two distinct layers of water, an upper layer or epilimnion and a lower colder layer or hypolimnion. The transitional zone between the two layers is known as the thermocline. In shallow, exposed lakes such thermal stratification may be transient, but in deep or less-exposed lakes the condition can become very stable. In the latter instance the activities of bacteria in the mud surface, and to some extent in the water above, cause the oxygen content of the hypolimnion to become progressively less as fresh supplies from above are cut off; in the immediate vicinity of the mud surface conditions may become anaerobic. On the other hand, water movements in the epilimnion vary widely and frequently as a result of changes in such factors as wind or atmospheric temperature, the temperature of inflowing rivers (or rain), and the temperature of the lake water. Figures 6 and 7 illustrate the different conditions which develop in the epilimnion and the hypolimnion.

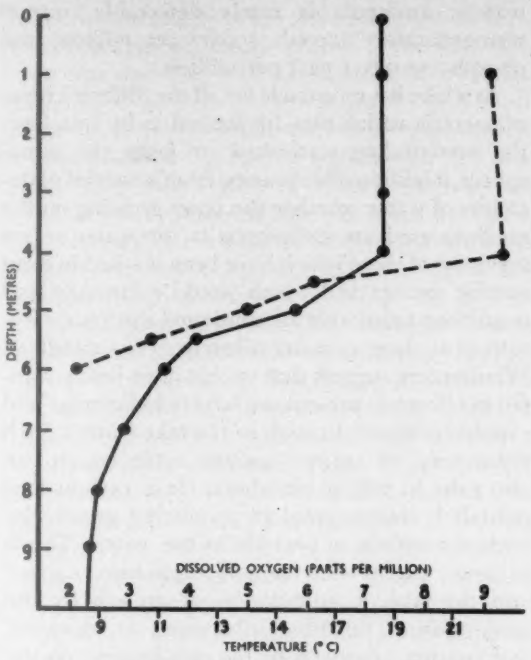


FIGURE 7 – *Blelham Tarn (Lancashire). Showing temperatures (solid line) and concentrations of dissolved oxygen (broken line) at different depths during period of stratification (8th August, 1947).*

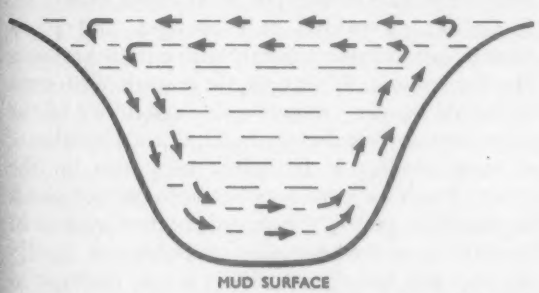


FIGURE 5 – *Diagram showing circulation of water in a lake during winter.*

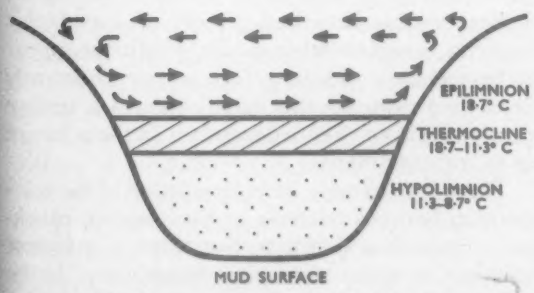


FIGURE 6 – *Diagram showing stratification of the water in a lake during the summer.*

The concentration of dissolved chemicals in a lake is influenced primarily by the quantity washed into it and the amount consumed by the phytoplankton and, to a much lesser extent, by the bacteria. The concentration of certain substances may be so reduced by the growth of various algae that the increasing population cannot be maintained; the growth of the diatom *Asterionella*, for example, is considered to be limited by the supply of its essential nutrient silica. In any case, the concentration in solution of chemicals essential for the growth of bacteria is extremely small in most lake

waters: ammonia is rarely detectable, nitrate nitrogen rarely exceeds 1 part per million, and phosphorus 0·004 part per million.

As a lake is a receptacle for all the different types of bacteria which may be washed in by rain from the surrounding watershed or from the atmosphere, it is impossible to assess from bacterial plate-counts of water whether the types growing on the medium used are indigenous to the water or are survivors of those which have been washed in from outside sources and which would eventually find conditions unsuitable for continued existence. Results of analyses of water taken from the middle of Windermere suggest that except after heavy rainfall the bacteria present are largely indigenous and capable of multiplication in the lake water. Such types may, of course, include some which can also exist in soil or elsewhere. It is certain that rainfall is instrumental in producing greatly increased numbers of bacteria in the water. This is to some extent due to soil organisms carried into the lake, to stimulation of growth by the washing-in of nutritive substances, to increased oxygenation produced by the rain beating on the lake surface, and possibly also to the disturbance of the surface layers by the purely mechanical effect. During the stratification which occurs in the summer, bacteria in the hypolimnion diminish in numbers and are affected only by those external factors strong enough to destroy or alter the stratification. Experiments carried out in Windermere over a period of more than a year have shown that faecal bacteria washed into the lake from the polluted river Rothay, its main inflow, soon perish. Thus the average count of *B. coli* in the main inflow below the discharge from the town's sewage works was 43,000 per 100 ml; after confluence with the river Brathay at the river mouth 500 metres distant it was 15,000 per 100 ml; at a point in the lake 170 metres from the river mouth, 1,400 per 100 ml; at 400 metres, 330 per 100 ml; and at 3,500 metres, 20 per 100 ml (figure 8).

The activities of the water bacteria are not clear. They are capable of multiplying in the meagre nutritive environment which lake water affords, and, in general, their population bears a rough direct relationship to the concentration of dissolved chemicals and the productivity of the lake. Such bacteria can belong to two main, but not distinctively different, nutritional types. The autotrophic bacteria are capable of obtaining their supplies of carbon from dissolved carbon dioxide and their energy from the oxidation of inorganic substances such as nitrogen, sulphur, or iron. The

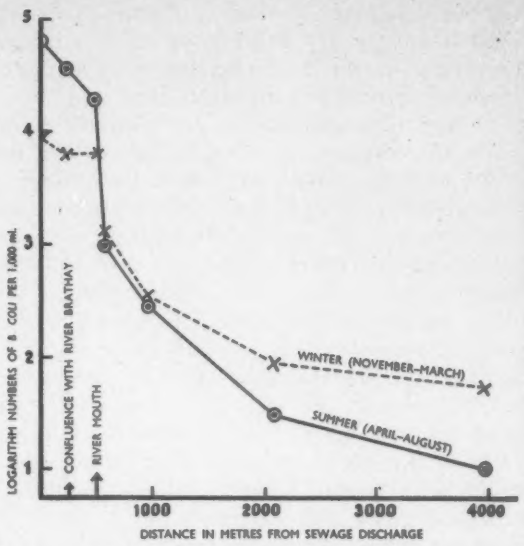


FIGURE 8 – *Average weekly numbers of* Bacterium coli, *indicative of faecal pollution, found at increasing distances from the point at which sewage is discharged into the river Rothay (broken line, winter months; solid line, summer months).*

heterotrophic bacteria are dependent on the carbon of preformed organic matter. Some organisms conform strictly to one type of nutrition; others are facultative. Provided that nitrogen and phosphorus are available, together with minute amounts of other essential substances, the growth of bacteria is limited by the amount and availability of the organic matter on the one hand, or the abundance of some oxidizable inorganic substance on the other. From such work as has been carried out it appears that part of the organic matter washed in from the watershed is readily available and rapidly decomposed, but the remainder is very resistant to attack by bacteria and consequently is broken down very slowly. The mere addition of appropriate inorganic substances does not necessarily initiate greatly increased growth of autotrophic bacteria, as certain other specific conditions appear to be necessary. There is, for example, constantly increasing evidence that nitrification is a surface phenomenon and hence dependent on the presence of particulate matter.

There is extremely little knowledge of the relationship between bacteria and the various planktonic animals and plants, but there is sufficient evidence to warrant certain assumptions. As the primary producers of organic matter in lake water, algae are a potential source of food for bacteria;

part of their substance, such as the siliceous skeletons of diatoms, may be totally unavailable, but on the other hand the complex polysaccharides found in the mucoid capsules surrounding certain types of algae may be readily available for decomposition. The presence of pectic substances in some types of algae can be detected by chemical analysis or staining methods. Thus it seems likely that part of the dead algal cell may be rapidly decomposed by bacteria in the water. Processes involving the more resistant organic matter continue after the cell has settled on the bottom of the lake. There is the further possibility of a symbiotic or parasitic relationship between algae and bacteria. It has also been suggested that some algae may excrete amino-acids, and if proof of this were obtained it would seem likely that bacteria would find the vicinity of the algal cell to be particularly favourable for growth. A third possibility is that some types of bacteria which are dependent for their continued existence on a site of attachment might find temporary accommodation on dead algal cells. Experiments show clearly that there is at least a much greater population of bacteria in a concentrated sample of plankton than in the original water from which the concentrate was made. The interrelationship between the zooplankton and the bacteria in a large body of water is still not clear. Simple laboratory experiments show that many types of animals such as rotifers, which feed on particles, will ingest bacterial cells in large numbers. The effect of planktonic animals in controlling or reducing the numbers of bacteria in lake water is uncertain, but on the other hand the dead planktonic animal must prove to be a ready source of food for bacteria.

It appears probable that the surface of the lake mud is by far the most active site for microbiological activity in the water/plankton/mud complex. The numbers of bacteria in mud, as determined by plate-counts, are of the same order as those in garden soils, and it has been found that when sufficient oxygen is present in the water lying immediately above, the common biochemical processes which normally occur in soils also take place in the mud. This is not surprising in view of the fact that there is a constant deposition on the mud surface of partially decomposed planktonic cells, washed-in silt, inorganic matter, and often appreciable deposits of leaves in the early winter. It is obvious that the nature of the surrounding terrain, whether wooded, agricultural, or rocky, and the density and type of plankton in the water, directly influence the nature of the sediments. Under aerobic conditions organic matter is broken down to ammonia and the ammonia is oxidized to nitrate. Organic compounds of sulphur are oxidized to sulphates, and inorganic phosphorus is regenerated in a form available for further assimilation. In relatively deep lakes such as Windermere aerobic conditions are always maintained, and it is assumed that the rate of the various biochemical reactions is governed by temperature, the approximate seasonal range of which is only 4–8° C. In some shallower lakes in Britain the lower layers of the hypolimnion can become exhausted of oxygen during warm weather, and the mud system becomes reduced; in exceptionally deep lakes this condition may be permanent. Such a state of affairs results in reduction of nitrates to ammonia, of sulphates to hydrogen sulphide, and of iron compounds to soluble ferrous salts. If the lake is used as a public water-supply and stratification happens to be disrupted by a violent autumnal gale, these compounds become mixed with the water in the upper layers of the lake and may result in a temporarily unpalatable water. There seems to be considerable evidence that rare and rather mysterious outbreaks of growth of certain—usually autotrophic—bacteria in lakes may be initially due to the production of reduced substances in the hypolimnion. A unique example of such a phenomenon took place in the late autumn of 1946. A large storage reservoir, which received chlorinated water of a high degree of chemical and bacterial purity and served an industrial town, turned visibly purple in colour. It was discovered that the colour was due to the presence of large numbers of an autotrophic bacterium capable of oxidizing sulphur and of producing a purple colour within the cell. A particularly mysterious aspect of the phenomenon was the origin of the relatively large amount of sulphur which must have been required to supply the energy for the development of such a vast number of bacterial cells.

Sterilization of water-supplies by the application of chemical substances is not a universal cure for the various bacterial troubles with which the industrial user of water is confronted. Typical difficulties are the blocking of mains by the growth of iron bacteria, the production of slimes, corrosion, and the development of undesirable tastes and odours. The basis of treatment lies primarily in seeking information concerning the nutrition of the responsible organisms and then preventing the establishment of conditions favourable for growth.

Some symbols used by the alchemists

DENIS I. DUVEEN

Alchemy may be studied from two points of view: as the primitive craft from which the modern science of chemistry arose, or as a system of mystical philosophy which endured for nearly 2,000 years. From both aspects, however, the important part played by symbols in alchemy is apparent, and the historian finds no lack of material upon which to exercise his skill in identification and interpretation. Mr Duveen describes some typical examples.

In the majority of their works the alchemists deliberately set out to baffle the uninitiated and to conceal their *modus operandi* from the public by the use of symbols. Thus the seven known metals were represented graphically by the astrological signs for the seven planets (including the sun and moon), and chemical operations were represented by various symbols, the true meaning of which was occasionally comparatively obvious. For example, a flock of birds flying upwards indicated sublimation or evaporation and flying downwards precipitation or condensation.

In such pictorial representation the symbolism frequently varied, but the figure of a king clad in red was used to denote gold and a queen in white to indicate silver. A yellow lion was sometimes employed to represent the yellow metallic sulphides, a red lion to symbolize the naturally occurring red sulphide of mercury (cinnabar), a green lion for salts of either copper or iron, an eagle or a crow for the black metallic sulphides, a salamander for fire, a lion with wings for mercury and one without wings for sulphur, and a green lion for 'philosophic' mercury. Solution of gold or silver by an acid was represented by a green lion devouring the sun or the moon respectively (see figure 2), and whereas antimony used in the purification of gold was depicted as a wolf, lead used in the purification of silver was usually shown as a figure of Saturn. The figure of a dragon being killed by the sun and moon represented the combination of gold with silver. Such allegories as death, burial, and putrefaction were frequently used in describing purely chemical operations in symbolical language, and the wedding of man and woman to represent the perfection of substances.

FIGURE 1 – *Explanation of alchemical symbols. (From an early eighteenth-century Low German alchemical manuscript.)*

FIGURE 2 – *The green lion devouring the sun.* (*From an early eighteenth-century Low German alchemical manuscript.*)

FIGURE 3 – *An adept giving instruction to his pupil.* (*From a hand-coloured copy of Mylius's* Philosophia Reformata (*Frankfurt*, 1622).)

FIGURE 4 – *A pictorial enigma representing the alchemical synthesis.* (*From* Les Douze Clefs de Philosophie de Frère Basil Valentin (Paris, 1649).)

FIGURE 5 – *Symbolical representation of the decoction of various ingredients to prepare the philosopher's stone.* (*From an early eighteenth-century Low German alchemical manuscript.*)

FIGURE 6 – *Alchemical apparatus and symbols of the four Evangelists.* (*From an illuminated early seventeenth-century manuscript of the* Livre de la Sainte Trinité.)

Figure 3, which is taken from the author's copy of Mylius's *Philosophia Reformata* (Frankfurt, 1622), in which the engravings are contemporaneously hand-coloured, shows two men chatting beneath the tree of universal knowledge. The four elements (inherited from Aristotle) are here clearly shown: earth by a man and a lion, fire by a dragon (both in the left-hand bottom corner), water by a woman riding a dolphin in the sea, and air by a bird, the last two symbols being found in the right-hand bottom corner. The figures of the two men represent Senior the adept instructing Adolphus the learner and author of the book. The seven circles round the outside of the tree symbolize the stages or operations involved in accomplishing the *magnum opus* and also the colour appropriate to each stage, colours being of great importance and significance to the alchemists in their work (cf. Hopkins: *Alchemy, Child of Greek Philosophy*, New York, 1934). Reading round the tree from the left-hand bottom circle, the symbols involved are (1) a crow and skull, representing the colour black and the operation of mortification; and (2) a pair of crows, depicting distillation; (3) three crows, symbolizing sublimation; (4) two birds and a crown, representing the accomplishment of the *opus minor* and the colour white; (5) two birds and a tree, indicating the reign of Mars; (6) a unicorn and a rose bush, depicting the colour red; (7) the end of the *magnum opus* and final preparation of the philosopher's stone by a new-born infant.

The alchemists also used enigmas to conceal their secrets; as a relatively simple one may be cited that attributed to the renowned but pseudonymous Basil Valentine (see figure 4), taken from *Les Douze Clefs de Philosophie de Frère Basil Valentin* (Paris, 1649).

This pictorial enigma is a complex synthesis of alchemical thought. The planets in the firmament are shown exercising their influence upon the important combination of the masculine and feminine principles represented here, as often, by the sun and moon. The chalice, like the cornucopia, is a symbol of mercury. Referring to the symbols in the lower half of the circle, we may note the two-headed eagle representing wind or air and the lion symbolizing land or earth. The orb depicts the philosopher's stone, and the seven-pointed star refers to the seven known metals of the earth which correspond to the seven planets in the heavens.

The words *Visita interiora terrae, rectificando inveries occultum lapidem* are specially interesting, for they form an acrostic, their initial letters spelling the word *vitriol*; this fact has been adduced to show that Basil Valentine was the discoverer of sulphuric acid!

Anagrams were also used extensively by the alchemists, although most of them are more or less impossible for the present-day student to decipher. As an example we may quote one which is to be found, accompanied by a ten-page commentary by Nicolas Barnaud, in the *Theatrum Chemicum* (vol. III, p. 744): '*Aelia Laelia Crispis* is my name. I am neither man, nor woman, nor hermaphrodite, nor virgin, nor young, nor old. I am neither a prostitute nor chaste but all these together. I am killed neither by hunger, nor by steel, nor by poison but by all these things at once. I rest neither in the sky, nor on earth, nor in the water but all over. *Lucius Agatho Priscius*, who was neither my husband, nor my lover, nor my slave, made me erect, without sorrow, without joy, without knowing for whom it was intended, this monument which is neither a pyramid nor a sepulchre but is both simultaneously. It is a grave which does not contain a corpse and a corpse which is not enclosed in a grave. The body and the sepulchre form but one entity.' Barnaud indicates in his commentary that we are dealing, in this enigma, with the philosopher's stone.

Figure 5 shows a symbol usually found associated with a treatise called *Der Hand der Philosophen*, attributed to Johannes Isaacus Hollandus. The illustration is taken from an early eighteenth-century manuscript and represents the decoction of the necessary ingredients for obtaining the philosopher's stone. In this particular instance our author has been specially considerate and has provided us with a clear diagram indicating the chemicals which each individual symbol is supposed to represent, as can be seen in figure 1, which is taken from the same manuscript. A good idea of the type of operation which Hollandus carried out can be gained from considering a translation of one of his recipes for accomplishing the *opus minor*, i.e. for preparing an elixir capable of transmuting baser metals into silver:

'Take one ounce of fine silver, dissolve it in common *aqua fortis*, then add four ounces of sublimed mercury to it in a glass pot. Set it on warm sand and let it become hot, then soak it with the *aqua fortis* in which the silver is dissolved until it has drunk up all the *aqua fortis*. Then let it cool. Pound this mercury quite fine on a hard stone. Let it dissolve of itself upon the stone, then coagulate again upon a small fire in a glass. Rub it down again as before, and dissolve as before, and so on

FIGURE 5 – *Symbolical representation of the decoction of various ingredients to prepare the philosopher's stone. (From an early eighteenth-century Low German alchemical manuscript.)*

FIGURE 6 – *Alchemical [illegible] illuminated early seventeenth-century manuscript of the* Livre de la Sainte Trinité.)

seven times. Of this elixir project one ounce upon thirty one ounces of prepared and well melted copper. So you will have fine silver, standing all tests.'

In addition to symbolism used to mask their proper operations, the alchemists frequently went to amazing lengths of extravagance in reading a hermetic meaning into ancient authors such as Homer and Virgil. The famous Michael Maier's most interesting work is the *Atalanta Fugiens* (Oppenheim, 1617), which is a complicated attempt to explain the fable of Atalanta and the golden apples by a hermetic analogy. The hermeticists were, however, not content with finding alchemical allegories in such fables as the wanderings of Ulysses but went farther and devised new and original ones, such as Béroalde de Verville's *L'Histoire Véritable, ou le Voyage des Princes Fortunéz* (Paris, 1610).

The very names which the alchemists gave to their tracts in many instances furnish a good indication of their flights of fancy, e.g. *The Marrow of Alchemy*, *The Triumphant Chariot of Antimony*, *The Amphitheatre of Eternal Wisdom*, *The Open Entrance to the Shut Palace of the King*.

The student of medieval alchemical literature cannot help being impressed with the frequent and apparently sincere invocations to God with which such works are usually adorned. The connection between alchemy and religion is traceable back to much earlier times, and is to be found in both Greek and Arabic alchemical writings. Connections between Christianity and alchemy went very deep, and we may cite Arnald de Villanova, the pseudo-Raimundus Lullus (it is generally agreed that the substantial body of alchemical literature attributed to Lullus was never written by the illustrious Majorcan but is the product of a later author), Petrus Bonus, and George Ripley as important alchemical authorities who made frequent use of a Christian allegory to illustrate alchemy.

The *Livre de la Sainte Trinité*, which was probably written at the time of the Council of Constance (1414–18), is a good example of the application of the allegory of the Passion, Crucifixion, and Resurrection of Christ to the realization of the *magnum opus* of alchemy. The author has dealt more fully with this particular symbolism elsewhere (*Ambix*, vol. III, No. 2), but the plate reproduced herewith (figure 6) will give a good idea of it. Beneath representations of four chemical vessels, each of which is intended for a particular operation, we find the conventional symbols for the four evangelists. These latter figures represent at once the four elements, the four principal stages of the work, and the four cardinal virtues.

Reference has already been made to the great importance which the alchemists attached to colour. In this connection they usually divided their work into three main colour divisions, namely the black, the white, and the red. The operations leading to the production of the philosopher's stone were supposed to proceed regularly through these three colours, and the symbolism connected with them is frequently encountered. Thus lead (Saturn) symbolizes black, silver (Moon) white, and copper red. Sometimes four colours are indicated instead of three, and then the colours may be symbolized by the four seasons of the year, as in the seventh key of Basil Valentine (*Les Douze Clefs de Philosophie*, Paris, 1659). They may also be represented by four birds, the crow symbolizing black, the swan white, the peacock violet, and the phoenix red (*vide* the pentacle associated with the ninth key of Basil Valentine, *op. cit.*).

In addition to pictorial symbolism the alchemists made much use of signs to denote various materials; a few of them are reproduced in figure 7. They made the unravelling of their processes particularly difficult for the modern chemist by a lack of uniformity in so far as the exact meaning of any particular sign was concerned, and also by the extremely large number of different ciphers frequently employed to represent the same material.

When attempting any serious understanding or evaluation of the alchemists and their works it is essential to remember that they usually belonged to quite separate and distinct classes. There were the operative alchemists who were the forerunners of the chemists of today: they were interested in studying the properties of metals and other simple and compound bodies and the most suitable methods and apparatus for their manipulation. These men made and recorded numerous important scientific discoveries; they may be exemplified by Libavius, Glauber, Ulstadt, van Helmont, and Croll. In a smaller class were the speculative chemists who believed the hermetic art to be of spiritual rather than physical attainment, its meanings being veiled in allegory and illustrated by symbols. The real object of their studies was the human soul and their aim mankind's spiritual regeneration and guidance to salvation: as typical representatives of this category Khunrath, Vaughan, Fludd, and Maier may be mentioned.

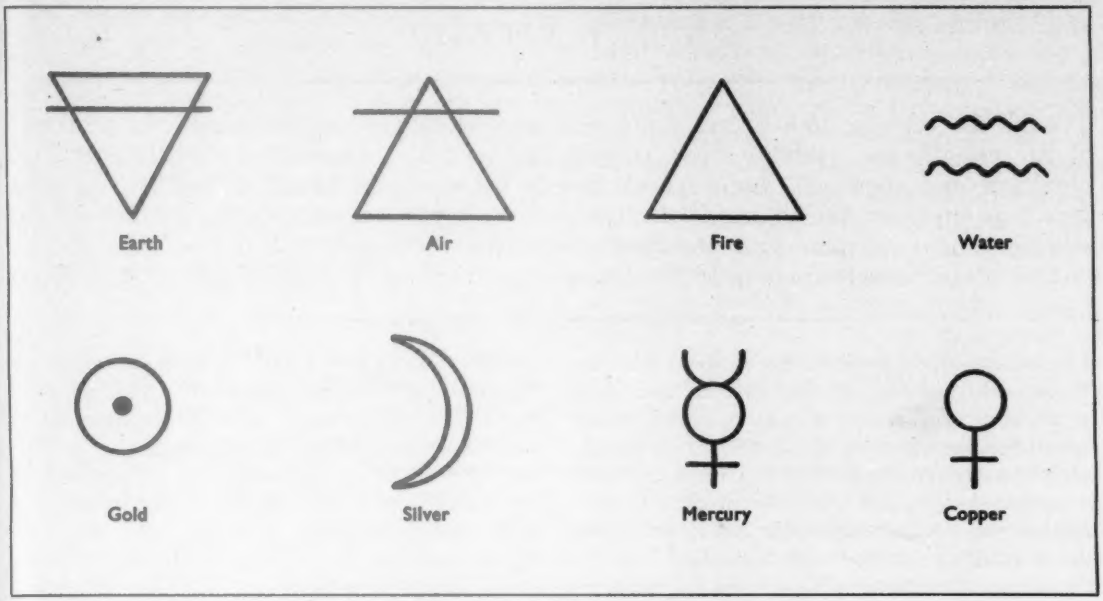


FIGURE 7 – *Early alchemical symbols.*

However, there was a third class which, though not very numerous, brought great discredit on alchemy: it comprised the mercenary mountebanks, puffers, and charlatans who persuaded princes and others to part with large sums of money in the hope of receiving the secret of the philosopher's stone which could transmute all baser metals into gold. Of such men Honauer, Caetano, Bragadino, and Cagliostro were among the most notorious and among those of whose final exposure we have details. As an example of the method of imitating gold and the fate which awaited the operators we may quote the tale of M. Longeville as recounted by Boyle Godfrey in his *Miscellanea vere Utilia or Miscellaneous Experiments and Observations on Various Subjects* (London, n.d. but *circa* 1735):

'*The Process by which Longeville Imitated Gold, for which the Dutch boyled him alive in Oyl, was this*—

'Take Copper four ounces, calcine it with common sulphur till it comes to an Ounce and Quarter, which must be done by several red-hot-makings and when it becomes green it is enough, then take this calcined Copper and an ounce of Silver and half an ounce of Borax, melt them very well together, then cast it out of the Crucible, and beat off the Dross, and melt it again with as much Borax, cast it out again, and beat off the Dross as before, repeating this work a third time, then melt it again by itself in a strong Fire, adding thereto two Ounces of Gold, let it stand a while in Flux, add some Borax to it and keep it there an hour then cast it out into Ingots, repeating the fluxing till the Borax remains white, then melt this artificial Gold alone, and cast into it Grains of Nitre, till it has got a good large Skin on the top of it, then cast it into Ingots, and it is done.

'So far the Receipt as communicated to me by a German Professor of an University.

'What Faults this Man committed in his Time I know not, but I regret his Death if it was for Gold-making, for I think this process far from that; however, be it as it will, a Friend of mine knows a Gentleman who saw Longeville cast down an hollow Wooden Thing into a cauldron of boyling Oyl, when he stood so nigh it, that some of the Oyl flew on his cloaths.'

The masonry arch

A. J. S. PIPPARD

Though the voussoir arch is one of the most ancient engineering structures, the problems of its strength and stability have proved unexpectedly enigmatic to mathematicians, physicists, and engineers. Indeed, until shortly before the outbreak of war in 1939 very little was precisely known about the behaviour of such an arch during increased load leading to final collapse. Professor Pippard describes systematic quantitative experiments, carried out by himself and some of his colleagues, which throw much new light on the subject.

The arch made of wedge-shaped blocks of stone, or voussoirs, is one of the earliest and most beautiful of engineering structures, and it would have been surprising if the attention of mathematicians and engineers had not been attracted to problems of its strength and stability. In fact, the many and varied explanations of its behaviour under load that have been advanced and the discussions to which they have given rise make an interesting chapter in the theory of structures. The earliest recorded investigations were made by mathematicians in the latter half of the seventeenth century, and as might be expected the first arguments were based on the properties of the inclined plane and wedge. It was assumed that the bearing faces of the voussoirs were highly polished and that failure of the structure occurred by slipping between some of them. In 1801 Atwood made experiments on arches with polished metal voussoirs, and the bridges designed by Rennie at the beginning of the last century were based more or less on these assumptions. A natural development was the investigation of the problem on the opposite assumption that the voussoir surfaces were infinitely rough so that slipping was prevented; failure could then occur only by the rotation of some of the voussoirs upon their edges, and this was experimentally demonstrated by Danisy. This, as will be shown later, is a first step towards the correct explanation of the mechanics of failure, but Couplet, who made the analysis, came to erroneous conclusions as to the location of the points of rupture.

Another line of approach, derived from analogy with the loaded catenary, was being developed simultaneously with this form of the wedge theory. It originated with Robert Hooke, who in 1676 included, in a *résumé* of inventions which he intended to publish later, the following passage: 'The true Mathematical and Mechanical form for all manner of Arches for Building with the true treatment necessary to each of them. A Problem which no Architectonick Writer has ever yet attempted, much less performed. abcccddeeeeefggiiiiiiiiill-mmmmnnnnnoopprrsssttttttuuuuuuuuvx.' The collection of letters is an anagram announcing in concealed form a new discovery, and its solution is *Ut pendet continuum flexile sic stabit contiguum rigidum inversum*, i.e. 'As the continuous flexible (cord) hangs downward, so will the contiguous rigid (arch) stand up inverted.' This appears to be the first statement of the idea of the linear arch which has exercised such a powerful influence upon the design of this type of structure down to the present day. It was the basis of Moseley's work in this country, and French mathematicians and engineers, including Navier, Clapeyron, Lamé, and Boistard, all made important contributions to the development of the theory. Navier in 1826 showed that if the linear arch cut a joint between voussoirs at one of the points which trisected its depth the joint would be just about to open. This early enunciation of the middle-third rule, as it became known later, was apparently overlooked; it was at any rate restated as a new idea in 1840 by Méry. Much of the work of the French writers was unknown in this country for a long time, and English theoreticians and engineers were making their own attempts at explanation. Moseley in 1835 and Snell in 1846 made important contributions, the latter getting near to the correct explanation of the cause of ultimate instability in the structure by the formation of hinge points between some of the voussoirs. His treatment, however, was faulty in essential details and strictly limited in application.

Robison about the same time became interested in the failure of an actual bridge made of rather soft stone which was ascribed to overloading at the crown. About a fortnight before the collapse occurred, bad cracking of the stones was observed

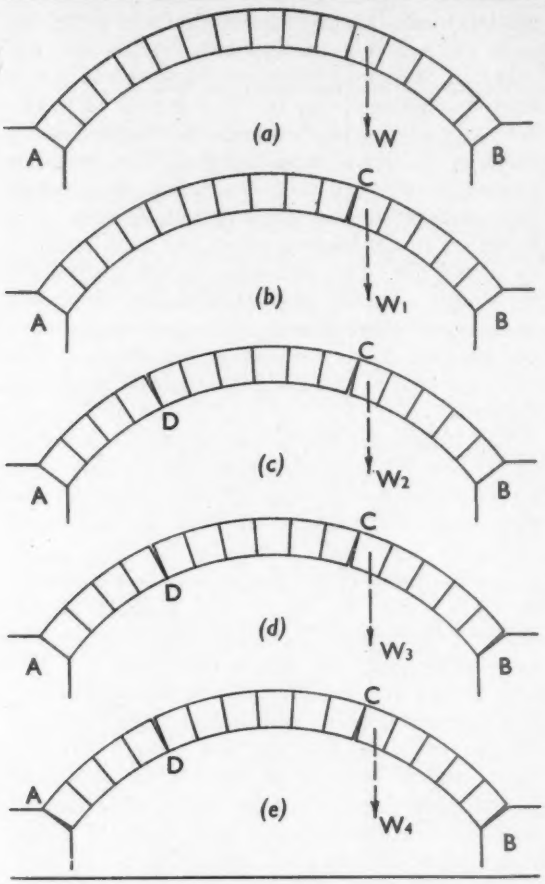
at 10 ft on each side of the crown and also at 20 ft on one side; it was considered by the masons that final failure would take place at these points, presumably by crushing of the stone. In fact, the collapse was quite different in character; segments of the arch pivoted about the crown, at points 15 or 16 ft on each side of the centre and also about points on the abutments. Robison is said to have reproduced the same type of failure in a model made of chalk voussoirs.

This very clear indication as to the lines upon which a solution might be found seems, however, to have been neglected; attention was again directed to the use of the inverted catenary or linear arch for design purposes. This arch received the powerful support of Rankine, who accepted as a fundamental canon of design that the linear arch must lie everywhere within the middle-third core of the structure so as to avoid the development of tension anywhere in the mortar joints. It is clear, however, that there is an infinite number of catenaries which can support a given system of loads, differing one from the other in their total length and in the value of the horizontal components of reactive forces, and so there will be an infinite number of linear arches satisfying the middle-third criterion. Considerable controversy was aroused over the selection of the correct linear arch, and it was not appreciated until much later that this was not a matter of more or less arbitrary choice but that every linear arch that could be drawn was associated with tacit assumptions as to movements of the abutments. If the abutments are to remain fixed, as would normally be hoped, only one linear arch is possible; any other requires the assumption of translational and rotational movements of one abutment relative to the other to satisfy the essential conditions of the problem.

The enunciation by Castigliano of his strain-energy theorems in 1879 provided a new approach, and in his book of that date he analysed a masonry arch by the principle of minimum strain energy, assuming in the first place that the arch was an elastic rib. When, as a result of analysis on this assumption, tension was found to occur, the portions of the arch in tension were assumed to be removed as being inoperative and a new analysis of the remaining structure was made. The process was repeated until a structure without tension resulted, from which the stresses were calculated. One objection to Castigliano's theory was the doubt as to whether a masonry arch exhibited a linear relationship between load and displacement, but this was satisfactorily settled by tests carried out on full-scale arches by the Austrian Society of Engineers in 1890 and much later by tests made by the Department of Scientific and Industrial Research in England on a number of actual road bridges. The Austrian engineers seem to have concluded in addition that, because the measured deflections were proportional to the loads applied, the arch behaved as a solid rib. This deduction is not justified by the simple evidence of proportionality, since, for example, a three-pinned structure would also exhibit such linear proportionality although the ratio between the quantities measured would be different.

The different assumptions as to the mode of failure which have been indicated in this brief survey—viz. by slipping if the voussoirs are frictionless, by pivoting if they are infinitely rough, by compressive failure of the stone, or by failure in tension of the mortar—are not mutually exclusive, and all types are possible under different conditions. The possibility of slipping is easily prevented, but, apart from that, the behaviour of a voussoir arch during the application of an increasing load until the occurrence of final collapse was still, in 1936, not properly understood, and it seemed of interest to approach the problem experimentally, since while simple qualitative experiments had been made by a few investigators no systematic quantitative tests had been attempted.

In 1936, therefore, the present writer and some of his colleagues began experiments to elucidate the behaviour of the voussoir arch. Model segmental arches were made with spans of 4 ft and rises of 1 ft 6 in, the voussoirs being carefully machined steel. One test arch had pinned ends while the other was supported on skewbacks. One end of the arch under test was fixed in position, but the other was mounted on a carriage made as free from friction as possible and restrained by a steel rod of small diameter carrying a delicate optical extensometer. The loads in this rod could thus be measured, and, the elastic stretch in the rod being taken up by a turnbuckle, the horizontal component of reaction at the free support was obtained direct. The arch was assumed to support a load of earth which filled the spandrels and formed a horizontal road surface, and this load was provided in the models by tins, appropriately weighted by shot, hung from the voussoirs. A point load of variable amount could in addition be applied to any voussoir.



In the first place, a solid rib of mild steel of the same dimensions as the voussoir arch was mounted as explained above. The dead loading remained constant, and the value of the thrust or horizontal component of reaction was measured for a range of loads applied to different points. From these a curve was drawn showing the thrust due to a unit load at any point in the span of the arch. The solid rib was then removed and the voussoir arch with pinned ends erected in its place. The experiment was repeated, and it was found that until a limiting load, which varied with the point of application, was reached the results were precisely as found for the solid rib. It was established, therefore, that within certain ranges, i.e. until certain limiting loads were reached, the voussoir arch behaved in exactly the same way as a solid rib. The limiting load is easily shown to be that which produces a tensile stress in a joint adjacent to its point of application and so reduces the bearing area of the voussoirs at that section. Attention was then concentrated on the behaviour of the arch when a gradually increasing load was applied to one voussoir, and the results which emerged can best be illustrated in diagrams.

The figure shows (*a*) a voussoir arch with its earth fill and in addition a load applied to a particular voussoir. As this point load is increased, the horizontal thrust at *A* also increases. For small values of *W* the thrust agrees practically exactly with the values for a solid rib of the same size and with similar abutments. At a value W_1 a change occurs in the ratio of the thrust to the applied load which is consistent with the formation of a pin at *C*, indicating that the arch has now effectively become two solid sections *AC* and *BC* pinned together at *C*, as shown at (*b*). If the supports are allowed to spread slightly, the 'pin' can be clearly seen to be formed by the hinging of the adjacent voussoirs at *C*. The new ratio of thrust to load is maintained for a time, but at a load W_2 another change occurs which is due to the formation of a second virtual pin at *D* (figure (*c*)). This pin is, however, on the intrados or underside of the arch, whereas the first one was on the extrados or outer side. The arch now consists of two solid sections *AD* and *BC* connected by a third solid section *DC* which is pinned to them, and it is essentially the structure of the cantilever bridge. A still further increase in the load shows that at W_3 there is another change in the ratio of thrust to load due to the formation of a third 'pin' at the intrados at *B*. The arch now consists of three solid sections of which one, *AD*, is *encastré* at *A*, the other two being effectively solid pin-jointed links (figure (*d*)). During this process there is a progressive reduction in the redundancy in the structure. The original arch, (*a*), has three degrees of redundancy, i.e. it may lose three reactive components and then become statically determinate: with the formation of each successive pin, one of these degrees of redundancy is lost, so that (*b*) has two, (*c*) has one, and (*d*) has none, i.e. (*d*) is a simple or statically determinate structure. If loading be continued beyond this value of W_3, a sudden collapse of the arch occurs at a load W_4 due to the formation of a fourth pin at *A* which turns the assembly into a mechanism.

These experiments clarified the mechanics of the voussoir arch and showed that while Snell's theory of failure advanced in 1850 had a sound basis it was inadequate and in certain respects faulty.

A real arch, however, is not composed of carefully machined steel voussoirs simply bearing on each other, but is normally built of dressed

masonry with joints of either lime or cement mortar. It has been accepted as a fundamental of design in masonry since Rankine's day that mortar joints ought not to be subjected to tensile stresses, and Rankine even stated that if such stresses developed in a masonry arch the structure became unstable. The experiments just quoted show that true instability does not occur until long after the first joint has cracked in tension; but the presence of a jointing material might be expected to have important effects upon behaviour, and so a second set of experiments was carried out in which the voussoirs were concrete blocks made with either granite or limestone chippings and the joints were made with either weak lime mortar or a strong cement mortar.

The arches of this series of experiments were also segmental, 10 ft in span and 2 ft 6 in. rise, and the dead load was applied in a similar way to that on the smaller steel arch. The general results of these experiments confirmed those previously obtained, but showed that even weak lime mortar was able to resist sufficient tensile stress to postpone the formation of the first virtual pin quite considerably. The cement mortar was very much more effective, and the arch made with it as a jointing material behaved as a solid rib over a much wider range of load than would be indicated by the assumption that the mortar was incapable of resisting any tension.

Interesting differences of behaviour were also apparent between the limestone and granite voussoirs. The former tended to crush and split when the virtual pins formed, but the granite gave a much stronger material and, when combined with cement mortar, gave a structure the behaviour of which agreed well with calculations made on the basis of tests on the idealized steel model.

One other set of experiments was in progress when war interrupted the work. The tests made so far had been concerned only with a single application of load to the structure, but an actual bridge is subjected to a repetitive load, and it was of some interest to determine whether this would seriously reduce the ultimate strength. The 10 ft span arches with concrete voussoirs were used for tests of this type, but instead of the point load being increased steadily until the structure failed, a fixed load was alternately applied and removed by means of a rocking lever, at a rate of about 65 cycles per minute.

When the first mortar joint cracked, a circuit was broken and the motor driving the rocking lever was automatically stopped. The number of cycles of loading applied was registered on a revolution counter.

A number of tests were made with the load applied at one particular voussoir, the magnitude of the load being varied. After one million reversals without break the load was increased and the process repeated until failure occurred. Both cement and lime mortar joints were tested, but it was possible to run only about twenty tests before interruption of the work. Enough was done, however, to indicate that although a repetitive load is more damaging than a single application, a masonry arch has a very considerable margin of strength beyond that usually ascribed to it by the conventional methods of design.

Book reviews

DETOXICATION OF ORGANIC COMPOUNDS

Detoxication Mechanisms, *by R. Tecwyn Williams. Pp.* 251. *Chapman and Hall Limited, London.* 1947. 16*s. net.*

The study of the fate of simple and complex organic substances in the body has attracted the interest of both the pharmacologist and the biochemist. Investigations during the second half of the last century—with which are linked the names of many famous pioneers of biochemical research such as Liebig, Hoppe-Seyler, Jaffe, Baumann, and others—have revealed the different mechanisms by which foreign substances are metabolized. This work and its immediate continuation by Knoop, Neubauer, Dakin, and others has also brought to light many facts of fundamental importance concerning the fate of normal metabolites, such as fatty acids and amino-acids.

In more recent times many new drugs have been introduced into medicine, and, though the study of their metabolism has not led to the discovery of any fundamentally new type of detoxication mechanism, many facts of interest have emerged from it. No comprehensive textbook on the fate of organic substances in the body has as yet been published, and therefore Dr R. T. Williams's book comes at an opportune moment and fills a gap in the literature. Dr Williams, who himself has made valuable original contributions to the field he reviews, has given a lucid and comprehensive account of the work, both classical and modern, on the metabolism of foreign substances. After a general discussion of the principal pathways of detoxication, and an interesting historical section, he has given a systematic account of a large number of organic substances of chemical or biological interest. Recent work of

topical interest, such as the metabolism of carcinogenic substances and the sulphonamides, and biological methylation, is included, and the more general implications for biochemical research are indicated. An extensive bibliography is provided, and Dr Williams's monograph should become not only a useful reference book for the specialist in the fields of toxicology, pharmacology, or biochemistry, but should also be of value to the student of chemistry or medicine.

E. CHAIN

THE ALPHABET

The Alphabet. A Key to the History of Mankind, *by David Diringer. Pp.* 608, *with* 256 *figures. Hutchinson's Scientific and Technical Publications, London.* 1947. 50*s. net.*

Far wider in scope than the title suggests, this work covers the whole field of writing—a paramount factor in civilization. Writing gives permanence to knowledge and survives, whereas speech changes.

From early signs and symbolic pictures the author traces the development of writing through various stages to the alphabet. The ideal alphabet is a distinct sign for each simple sound. We see how the alphabet follows the flag, trade, and religion, and how readily adaptable it is for reducing any spoken language to written form.

It appears that the alphabet was invented once only, but the place of origin is still undecided. Inscriptions in Sinai may be the link in development from Egyptian hieroglyphs. The Egyptians were alphabet-conscious and actually used a 24-letter alphabet. The author is not correct in stating that 'they never employed it without determinatives' (p. 63) and classes the script as non-alphabetic because many additional signs were generally used; these were helpful to the reader, since only consonants were written. He maintains that the alphabet was invented by certain Syro-Palestinian Semites.

Valuable historical notes, illustrations in profusion, and useful bibliographies contribute to the most comprehensive and detailed survey of the subject yet published. It is a fascinating story.

R. W. SLOLEY

PERMO-TRIASSIC FORMATIONS

The Permo-Triassic Formations: A World Review, *by R. L. Sherlock. Pp.* 367, *with* 15 *figures. Hutchinson's Scientific and Technical Publications, London.* 1948. 31*s.* 6*d. net.*

In general it is relatively easy to subdivide a succession of rocks in any limited area, by reference either to the fossils contained in them or even to vertical changes in the character of the rocks themselves. But to correlate the subdivisions appropriate to one area with those of another, particularly in a different continent or other hemisphere, may, on account of lateral variation in fauna and lithology, present one of the greatest difficulties which can confront the geologist. The Continental rocks laid down under the peculiar conditions of the Permo-Trias, which contain scarcely any fossils, present all these difficulties in an acute form, and the classification and correlation of the New Red Sandstone has long been a matter of contention. It formed one of the late Dr Sherlock's main interests for thirty or forty years, and this world review is his last contribution to the controversy. In brief, he claims that the Permian System, between the Carboniferous and the Trias, has no validity, but that all rocks so designated the world over are either Upper Carboniferous or Lower Triassic in age. It is impossible to detail here the arguments for or against such a view, but it is perhaps not unfair to label this a minority report. The book is essentially one for the specialist (who cannot afford to overlook it) rather than the general reader, in anticipation of which the publishers presumably felt obliged to price the book at 31*s.* 6*d.*

O. M. B. BULMAN

DE REVOLUTIONIBUS ORBIUM COELESTIUM

Nicolaus Copernicus. De Revolutionibus: Preface and Book I. *Translated by Professors J. F. Dobson and S. Brodetsky. Royal Astronomical Society: Occasional Notes, No.* 10. 1947. 3*s.* 6*d. net.*

Of the classics in the history of science which remain to be translated into English, none is more outstanding than the *De Revolutionibus Orbium Coelestium* of Copernicus. There is a modern German translation, which, however, violates the meaning of the original in the very title, referring to the heavenly *bodies* instead of the heavenly *spheres*. It is therefore most fitting that the Royal Astronomical Society has resumed the issue of its valuable *Occasional Notes* with an annotated English translation of the Preface and Book I (together with a biographical note, portrait, and facsimile of title page) by the late Professor J. F. Dobson of Bristol and Professor S. Brodetsky of Leeds. In view of the special interest of this publication the Society has broken its practice of issuing *Occasional Notes* only to its Fellows and made this number available to the general public. The translation has evidently been made with much care, and the collaboration of a classical scholar and a mathematician has ensured that it shall be trustworthy. There is a slight error in Professor Dobson's biographical note, which states that the earlier *Commentariolus* was known to Tycho Brahe 'before the publication' of *de Revolutionibus*. Since the latter was published in 1543 and Tycho was born in 1546, this would have been impossible. There is also an unfortunate slip in the diagram on page 30 of the translator's notes, by which the moon's orbit is printed as 'Mars's Orbit.' On the whole, however, the rendering is substantially accurate, and the Society is to be warmly thanked for making it generally available.

H. DINGLE

PRACTICAL ORGANIC CHEMISTRY

A Text-Book of Practical Organic Chemistry, *by Arthur I. Vogel. Pp. xxiv* + 1012. *Longmans, Green and Company Limited, London.* 1948. 42*s. net.*

This is an ambitious book, but it may be said at once that the ambition is fulfilled. Dr Vogel, whose previous books on qualitative and quantitative analysis are well known and appreciated, here distils for the benefit of students the experience of some twenty years of research and teaching in organic chemistry. After a brief consideration of the theory of general technique the author devotes nearly a fifth of the book to a discussion of experimental technique, including sections on chromatographic adsorption and the use of apparatus with interchangeable ground glass joints. The thoroughness of this discussion should be of the greatest possible value to both elementary and more advanced students. The main portion of the book gives careful and lucid instructions for more than 600 organic preparations, ranging from such simple substances as amyl nitrite and ethyl acetoacetate to such uncommon or complex ones as S-benzyl-*iso*thiuronium chloride and sulphapyridine. The experimental details provided make it quite clear that Dr Vogel realizes the points at which a student may be likely to err and has anticipated them.

The value of the book is enhanced by

the inclusion of a section on qualitative organic analysis, several tables of physical constants of organic compounds, and a bibliography (with a brief guide to *Beilstein* and a full index). The volume should find a place in the laboratory of every teacher and student of the subject.

THE ELECTRON MICROSCOPE

The Electron Microscope, *by V. E. Cosslett. Pp. viii + 128, with 12 plates and 39 figures. Sigma Books Limited, London.* 1947. *7s. 6d. net.*

This little book is intended to be an introduction to the electron microscope and its uses for the biologist and industrialist, who are not expected to have any special mathematical or physical knowledge. The book is, in fact, free from mathematics and relies on figures to make clear the physical principles involved in the construction and operation of the instrument. It can safely be recommended to any reader who wishes to have an elementary description of how this new instrument works and what kind of job it can do. Dr Cosslett also gives some indications of the present limitations and possible future developments of the technique.

The book contains seven chapters, the titles of which will serve as a guide to the contents. Starting with the eye and the (optical) microscope, the author then introduces the electron microscope and electron lenses. The magnetic and electrostatic types of instrument each receive a chapter, and mention is made of less orthodox types of microscope in which the object is scanned by an electron probe. The technique of specimen preparation, by replica and shadow-casting, occupies a chapter, and the book concludes with future possibilities.

There are a short bibliography and a useful index. G. D. PRESTON

GERMAN ATOMIC ENERGY PROJECT

Alsos—The Search for the German Atom Bomb, *by Samuel A. Goudsmit. Pp. xiv + 259. Sigma Books Limited, London.* 1948. *15s. net.*

Dr Goudsmit has written an entertaining account of the investigations into the German wartime activities in atomic energy which were made by the special American Alsos Mission, of which he was the chief scientist.

Reproductions or translations of German documents illustrate the astonishingly inefficient way in which the German scientific effort, apart from research sponsored by the Air Force and Navy, was organised. In view of the German reputation for organization this is surprising, but Dr Goudsmit brings out clearly the reasons for this failure and draws certain conclusions of a warning nature about the possibility of the same thing happening in the U.S.A.

The book may, however, give a totally wrong impression of the state of knowledge of the Allies about the German atomic energy project prior to the investigations conducted by Dr Goudsmit in the wake of the invading armies.

The reason for this is seen at the beginning of chapter II, where Dr Goudsmit explains that he had not worked on the American atomic bomb project, and it is clear that he cannot have had access to the reports on German activities prepared during the war by the British and American Intelligence organizations. There has been plenty of published evidence, from German documents discovered since the end of the war, to show that the British Intelligence organization was both very active and remarkably accurate in many fields. It would therefore be surprising if our knowledge of one section of German wartime activity were as non-existent as Dr Goudsmit suggests. On the contrary, it is not unreasonable to assume that during the war the British and American Intelligence services produced a picture of the magnitude and nature of the German atomic energy work which Dr Goudsmit's investigations subsequently showed to have been remarkably accurate.

Dr Goudsmit seems to have considered that he was employed on an Intelligence mission. Using this word in its usual restricted sense, this is not true—the mission was a very successful C.I.O.S. Mission. R. E. SLADE

TALK OF MANY THINGS

One Two Three . . . Infinity, *by George Gamow. Illustrated by the author. Pp. xii + 340. Macmillan and Company Limited, London.* 1947. *24s. net.*

The intriguing title of Professor Gamow's book evokes anticipations of yet another example of lucid exposition illuminated by a characteristic whimsical humour. Nor are we disappointed. The book is something of an *olla*, and there are learning, wit, and wisdom in it, 'all working in a delicious gravy.'

What are the particular ingredients of this savoury dish? The first of the four sections into which the book is divided is entitled *Playing with Numbers* and deals in lively fashion with such topics as big numbers, prime numbers, and imaginaries. We meet friends old and new, but always attractive; the story telling how a knowledge of the properties of $\sqrt{-1}$ would have helped in the discovery of buried treasure is most fascinating.

The second section (*Space, Time and Einstein*) is an admirably clear exposition of the basic concepts of modern relativity. The third section (*Microcosmos*) sets the modern views of atomic problems against an historical background, as does the last section (*Macrocosmos*), which deals with the problem of the evolution of our universe.

That difficult but engaging fellow, the Inquiring Layman, will not find the book easy reading—the new ideas are difficult to minds nurtured in Newtonian traditions. But let him persevere to the end—he will be amply rewarded.

ALLAN FERGUSON

MAGNETIC MATERIALS

Magnetic Materials, *by F. Brailsford. Pp. ix + 156, with 86 diagrams. Methuen and Company, London.* 1948. *6s. net.*

In this monograph the author, who is a member of the research department of Metropolitan-Vickers and who has made a number of contributions in this field, gives a comprehensive though necessarily brief outline of the present knowledge of the subject. It is suitable for advanced students, research workers, and those concerned with the applications of magnetic materials. In addition to a general list of books and summarizing articles, each chapter is provided with a very full list of references. After an introduction, succeeding chapters deal with ferromagnetism, single crystals, factors affecting magnetic properties (including cold working, vibration, and magnetostriction), silicon-iron alloys, nickel-iron alloys, and permanent magnets. In all these subjects remarkable advances have been made during the last thirty years.

At the very beginning, when discussing a permanent magnet free to rotate, the datum level of energy is taken as that when the magnet is at right angles to the field, 'the potential energy then being zero,' which it obviously is not. This introduces unnecessary minus signs and probably

accounts for the occurrence of such terms as 'it will be clear that' and 'clearly, if' four times on this single page. On page 7, $\mu_{max.} = 6{,}000$ appears to be a misprint for 4,000. An interesting point explained on page 6 is that the magnetic force *H* in oersteds is never employed; the author always uses the equivalent value of the magnetic induction *B* in a vacuum expressed in gauss, but refers to it as *H*. Although the author refers to his own work on rotational hysteresis, he apparently gives no reference whatever to either Swinburne, who first suggested the existence of the phenomenon, or F. G. Baily, who first confirmed it experimentally. The book can, however, be unreservedly recommended to anyone interested either in the theory or in the manufacture and application of magnetic materials.

G. W. O. HOWE

THE DISCOVERY OF NEPTUNE

John Couch Adams and the Discovery of Neptune, *by W. M. Smart. Pp.* 56, *with* 3 *plates. Royal Astronomical Society, London.* 1947. 5*s. net.*

The occasion of this monograph was the commemoration in 1946 of the centenary of the discovery of Neptune, and excerpts from it formed the subject-matter of two addresses given by Professor Smart at the celebration arranged by the Royal Astronomical Society. A full-length biography of Adams has never been written; but all his letters, papers, and diaries were carefully preserved and came into the possession of his close friend, Sir Donald MacAlister, on whose death they were entrusted to Dr Smart, then the first John Couch Adams Astronomer of the University of Cambridge. Professor Smart has used these private papers in the preparation of this full account of the circumstances connected with the discovery of Neptune. The broad outline of these circumstances and the violent controversies in France and England which followed the discovery are well known, but Professor Smart has given many details and extracts from letters which have not previously been published and which could not have been published while any of the protagonists were alive. The one criticism of what is intended to be an historical account is a marked bias against Airy, which would possibly be corrected if Professor Smart were to read Airy's correspondence of this period. The monograph concludes with a brief account of the career of Adams subsequent to the discovery of Neptune.

H. SPENCER JONES

INFRA-RED PHOTOGRAPHY

Photography by Infra-red, *by W. Clark. Pp. xvii* + 472. *Chapman and Hall Limited, London. Second edition.* 1946. 36*s. net.*

Recent marked interest in the application of infra-red measurements to chemical problems has concerned mainly the wavelength range 2 μ (20,000 A) to 25 μ. This region is inaccessible by direct photography, but vast improvements have been achieved in other methods of detection and measurement. Many of the new detectors can be used with advantage in the photographic range 0·7–1·2 μ, and will now be preferred for some research problems and certain applications. For a wide variety of measurements, however, both pure and applied, photography will still be required and is more suitable. This book, by a member of the staff of the Eastman Kodak Company, provides an excellent survey of both the principles and practice, and incorporates a wealth of information on the subject. There are clear expositions of the basis of sensitization, of the salient photographic theory, and of the chemical and physical background, as well as much helpful technical guidance for the uninitiated. Typical applications are described and illustrated in many fields such as art, papyrology, criminology, medicine, botany and palaeontology, aerial survey work and camouflage, spectroscopy, and astronomy. Such aspects as sources of radiation and filters are discussed in detail. The lucid historical background adds interest for all, and the extensive up-to-date bibliography will be valuable to both specialist and general reader. Some repetition in different sections of the book does not diminish its value. The author aptly and justly refers to the much-forgotten contributions of R. W. Wood in this field. A useful book.

H. W. THOMPSON

SOLUBILITY TABLES

Solubilities of Inorganic and Metal Organic Compounds (*Vol. I*) *and* Solubilities of Organic Compounds (*Vol. II*), *by Atherton Seidell. Pp.* 1698 (*Vol. I*) *and* 926 (*Vol. II*). *Macmillan and Company Limited, London* (*for D. Van Nostrand, New York*). *Third edition.* 1947. 85*s. net* (*Vol. I*) *and* 75*s. net* (*Vol. II*).

The last completely revised edition of this well-known work of reference appeared in 1919, and a supplementary volume was published in 1928. Since that date a great many new data have been compiled, and the publication of this third and completely revised edition is therefore an important event. That the new edition consists of two large volumes in place of the previous single one is in itself an indication of the amount of new material which it has been necessary to include.

The arrangement of the data has been improved. In particular, a purely chemical system, based upon the chemical symbols of the elements, replaces the former arrangement based upon the English names of the compounds. This should considerably increase the value of the work to those whose knowledge of English is limited.

While the number of data listed has been increased and ease of reference has been improved, this edition is typographically inferior to previous ones. This is due to the fact that the work has grown so large that printing by ordinary methods would have rendered its price prohibitive. Offset printing from microfilm copies of original papers has therefore had to be used, with the result that the text is indistinct in places, though it is nowhere illegible. Although this defect would be intolerable in a book which had to be read continuously, it does not seriously detract from the value of a work such as this, of which only short sections are needed at any one time. This method of printing has at least one advantage which is important in a book consisting chiefly of long numerical tables, namely that the risk of errors in copying is greatly reduced.

Notes on contributors

E. CHAIN,
D. Phil.,

Was born in 1906 in Berlin, but is of Russian descent. The son of an industrial chemist, he graduated in Germany in chemistry and physiology. Political events caused him to come to England in 1933, and he has since acquired British nationality. He worked for two years at Cambridge in Sir F. Gowland Hopkins' laboratory, and is now University Demonstrator in Chemical Pathology at Oxford in the Sir William Dunn School of Pathology. He has always been interested in the biological aspects of chemistry and has played a leading part in the chemical investigation of penicillin, on which he writes in this issue of ENDEAVOUR. This work gained for him a Nobel Prize for Physiology and Medicine in 1945. In 1947 he was elected a Commander of the Legion of Honour. His work on penicillin has brought him high awards from universities and scientific institutions throughout the world.

ENRICO TORTONESE,
D.Sc.,

Was born in 1911 and was educated at the University of Turin. Since 1932 he has been assistant in the Museum and Institute of Zoology in this university. In 1939 he undertook the additional work of Lecturer in Zoology, in which capacity he has been principally concerned with hydrobiology. His chief interests are in problems of systematics, zoogeography, and ecology, with particular reference to marine biology, and he has published many papers on these subjects. He has carried out field studies in Tripolitania, Rhodes, and the Middle East. His other interests include the history of biology.

P. H. T. HARTLEY,
B.Sc.,

Was born in 1909 and was educated at University College, London, specialising in zoology. He has worked at the Plymouth Laboratory of the Marine Biological Association and at the Barrington and Windermere laboratories of the Freshwater Biological Association. He is now a member of the staff of the Department of Zoological Field Studies at Oxford. During the recent war he served as a camouflage officer in the Middle East and in 1944 commanded the Middle East Camouflage School.

IAN RAWLINS,
M.A., M.Sc., F.R.S.E., F.Inst.P.

Born in London in 1895, he was educated privately, then at the University of Edinburgh, Trinity College, Cambridge, and the University of Marburg. After graduating he became Director of Studies at Fitzwilliam House, Cambridge, and later University Research Assistant in Crystallography. Since 1934 he has been the first scientific adviser to the Trustees of the National Gallery, London, head of the research laboratory there, and Assistant Keeper since 1945. In 1939 he was Visiting Lecturer at Harvard University and Robert Trowbridge Memorial Lecturer at Yale University. In 1947 he was again Visiting Lecturer at Harvard University, and Fenton Foundation Lecturer in the University of Buffalo. He has published numerous papers in *Technical Studies in the Field of the Fine Arts* and other journals dealing with the application of physics and chemistry to paintings and with the philosophical psychology of art. He edited *From the National Gallery Laboratory*, published in 1940. He is a student of ecclesiastical architecture.

CHARLES B. TAYLOR,
B.S.A., Ph.D., D.Sc., F.R.I.C.,

Was born in 1908 and was educated at King Edward VII School, Sheffield, McGill University, Montreal, and London University. After investigating problems relating to the microbiology of soils and of milk-factory effluents he returned to Canada to work on soils at the Dominion Agricultural Station, Ottawa. In 1938 he was appointed the first bacteriologist to the Freshwater Biological Association at Ambleside, England. During the recent war he worked with the staff of the Water Pollution Research Laboratory to develop methods for the purification of effluents from factories for retting flax; this was a new British industry made essential by the German occupation of Belgium and France. Results obtained in the course of this project led to the development of a method of retting flax with an aerated solution in which repeated use is made of the same retting liquor. In 1946 he returned to the Freshwater Biological Association to re-establish a bacteriological laboratory for investigating fundamental problems relating to the activities of bacteria in water and in lake muds. He has published papers on the bacteriology of soils, waters, flax, and corroded concrete.

DENIS I. DUVEEN,
F.R.I.C.,

Was born in 1910 in London and was educated at Rugby School and Merton College, Oxford. He spent the years immediately preceding the recent war on research work, first at Battersea Polytechnic and then at the Collège de France, Paris, during which time he published a number of papers on optical activity in unsaturated secondary alcohols and on the chemistry of the naphthacenes. After a spell as chemist in the Royal Gunpowder Factory he spent the major part of the war as technical assistant in the Directorate of Ordnance Factories (Explosives) at the Ministry of Supply. He is now Joint Managing Director of Ashe Laboratories Ltd., London, and has published since the war a number of papers on historical and bibliographical matters relating to the history of chemistry.

A. J. S. PIPPARD,
M.B.E., D.Sc., M.I.C.E.,

Was born at Yeovil, Somerset, and was educated at Yeovil School and the University of Bristol. After training as a civil engineer he joined the Pontypridd and Rhondda Joint Water Board, but in 1915 he was appointed to the Admiralty Air Department for aircraft structural work. After the end of the 1914–18 war he was a partner in the consulting firm of Ogilvie & Partners until his appointment to the Chair of Engineering at Cardiff University College in 1922. In 1928 he succeeded Professor R. M. Ferrier as Professor of Civil Engineering in the University of Bristol and in 1933 became Professor of Civil Engineering in the University of London at Imperial College, a post which he still holds. He is a member of council of the Institution of Civil Engineers and author of a number of technical papers and books.

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